Proceedings of an Academy of Science of South Africa Forum

CRITICAL ISSUES IN SCHOOL MATHEMATICS AND SCIENCE: PATHWAYS TO PROGRESS

30 September to 2 October 2009
University of Pretoria

Applying scientific thinking in the service of society

ASSAf
ACADEMY OF SCIENCE OF SOUTH AFRICA

ISBN: 978-0-9869835-1-1

Published by:

Academy of Science of South Africa (ASSAf)

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996 in the presence of then President Nelson Mandela, the Patron of the launch of the Academy. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science for the benefit of society, with a mandate encompassing all fields of scientific enquiry in a seamless way, and including in its ranks the full diversity of South Africa's distinguished scientists. The Parliament of

South Africa passed the Academy of Science of South Africa Act (Act 67 in 2001) *which came into operation on 15 May 2002.*

This has made ASSAf the official Academy of Science of South Africa, recognised by government and representing South Africa in the international community of science academies.

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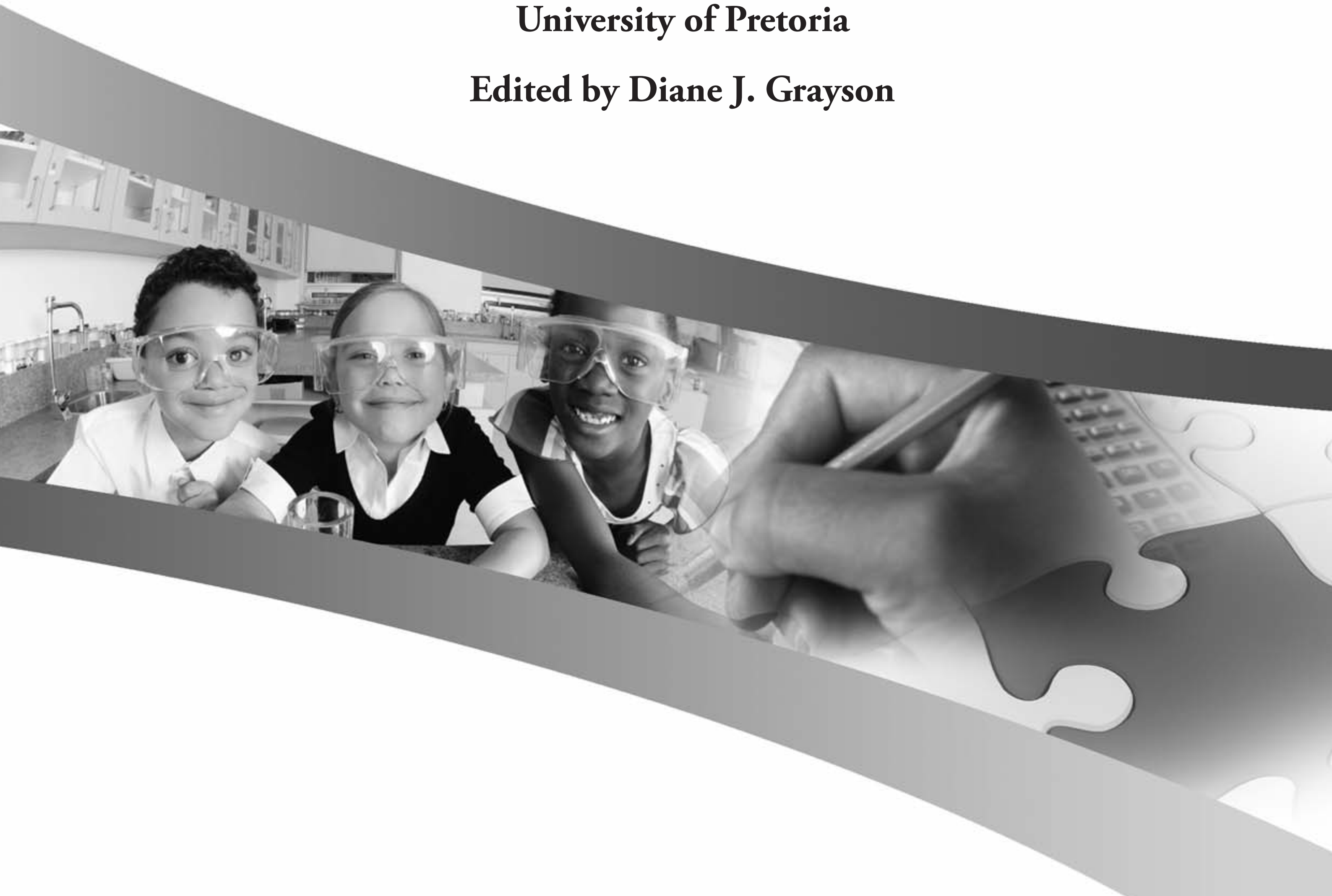

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Acronyms and Abbreviations

ABET	Adult Basic Education and Training
ACE	Advanced Certificate in Education
AMESA	Association for Mathematics Education of South Africa
ANC	African National Congress
ASGISA	Accelerated and Shared Growth Initiative for South Africa
ASSAf	Academy of Science of South Africa
AUTC	Australian Universities Teaching Committee
BA	Bachelor of Arts
BE(Ed)	Bachelor of Arts (Education)
BEd	Bachelor of Education
BEng	Bachelor of Engineering
BProc	Baccalaureus Procurationis
BSc	Bachelor of Science
BSc (Ed)	Bachelor of Science (Education)
CASS	Continuous assessment
CESM	Classification of Education Subject Matter
CHE	Council on Higher Education
CIE	Cambridge International Examinations
CPD	Continuing Professional Development
CPTD	Continuing Professional Teacher Development
CUP	Committee of University Principals
D	Difficult
DBE	Department of Basic Education (since April 2009)
DHET	Department of Higher Education and Training (since April 2009)
DoE	Department of Education (prior to April 2009)
DSE	Diploma in Secondary Education
DST	Department of Science and Technology
E	Easy
ECP	Extended Curriculum Programme
FDE	Further Diploma in Education
FET	Further Education and Training
FETC	Further Education and Training Certificate
FP	Foundation Phase (grades R–3)
FYLIA	Foundation for Youth Leadership in Agriculture
GET	General Education and Training
ha	Hectare
HDE	Higher Diploma in Education
HE	Higher Education
HEI	Higher Education Institution
HESA	Higher Education South Africa
HG	Higher Grade
Hons	Honours
HRMIS	Human Resources Management Information System
HSRC	Human Sciences Research Council
HSRP	Historic Schools Restoration Project
ICMI	International Commission on Mathematical Instruction
ICSU	International Council for Science
IMF	International Monetary Fund
IP	Intermediate Phase (grades 4–7)
IRT	Information Response Theory
ISLE	Investigation-based Science Learning Environment
IT	Information Technology
LiEP	Language in Education Policy

LLM	Master of Laws
LO	Learning Outcome
LoLT	Language of Learning and Teaching
LPG	Learning Programme Guidelines
M	Medium
MIT	Massachusetts Institute of Technology
MST	Mathematics, Science and Technology
NATED	National Education (Curriculum)
NBT	National Benchmark Tests
NCHE	National Commission on Higher Education
NCS	National Curriculum Statement
NCV	National Certificate (Vocational)
NGO	Non-Governmental Organisation
NIKSO	National Indigenous Knowledge Systems Office
NPDE	National Professional Diploma in Education
NPFTED	National Policy Framework on Teacher Education and Development
NQF	National Qualifications Framework
NSC	National Senior Certificate
NSMSTE	National Strategy for Mathematics, Science and Technology Education
NSTF	National Science and Technology Forum
NRF	National Research Foundation
OBE	Outcomes-based Education
OECD	Organisation for Economic Cooperation and Development
Palama	Public Administration, Leadership and Management Academy
PC	Postgraduate Certificate
PGCE	Postgraduate Certificate in Education
PhD	Doctor of Philosophy
PME	Psychology of Mathematics Education
QUANTUM	Qualifications for Teachers Underqualified in Mathematics project
SAATA	South African Agricultural Teachers Association
SAASTA	South African Agency for Science and Technology Advancement
SAASTE	South African Association of Science and Technology Educators
SACE	South African Council for Educators
SACI	South African Chemical Institute
SADC	Southern African Development Community
SAG	Subject Assessment Guidelines
SAMF	South African Mathematics Foundation
SAQA	South African Qualifications Authority
SCALE-UP	Student-centered Activities for Large Enrollment Undergraduate Programmes
SET	Science, Engineering and Technology
SETA	Sector Education and Training Authorities
SGS	Standard Grade
SoTL	Scholarship of Teaching and Learning
SP	Senior Phase (grades 8–9)
STEM	Science, Technology, Engineering and Mathematics
STM	Science, Technology and Mathematics
SYSTEM	Students and Youth into Science, Technology, Engineering and Mathematics
TIMSS	Trends in International Mathematics and Science Study
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organisation
US/USA	United States of America
UWC	University of the Western Cape
Wits	University of the Witwatersrand

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Foreword

The state of science and mathematics in South African schools has frequently been termed a national crisis. South African learners have fared poorly in comparative tests of science and mathematics at both international and regional levels and in local benchmark texts. This is true at both primary and secondary levels. These averaged results mask a very wide disparity between learners: a small minority continue to make significant progress in these subjects, while the majority fail to perform at appropriate levels. As a result, the pool of potential scientists, engineers, health practitioners and future teachers of mathematics and science is severely limited. This, in turn, limits South Africa's ability to be internationally competitive, as well as its ability to provide the infrastructure needed for the wellbeing of the majority of its people.

2009 was a seminal year for education in South Africa as the first recipients of the new National Senior Certificate (NSC) entered higher education, and in larger numbers than in the past. These students were also the first ones to have gone through 12 years of post-apartheid schooling with an outcomes-based curriculum. Outcomes-based education was chosen as an educational philosophy to undergird the new curricula in order to enable each South African child to achieve his or her full potential. It was believed that setting the outcomes to be achieved at the end of the learning process would encourage a learner-centred and activity-based approach to education, in direct contrast to the teacher-centred, passive learning practice that had marked South African education in the past. This radical change in the approach to education took place in the context of a critical shortage of technical and professional skills in science and technology-related fields, and amid concerns about the capabilities of school-leavers as compared with those of a decade ago.

The NSC, and particularly the requirements related to mathematics and entrance into higher education (HE), succeeded in releasing what had been a considerable blockage to entry to HE. More entrants, however, have not led to greater numbers of students succeeding. There are early indications that overall student performance in science-based programmes at higher education institutions (HEIs) is below that of previous years. The larger intake resulted in larger numbers of students performing very poorly in their mid-year assessments. HEIs mounted various interventions to prevent a large failure rate of first-year students. It has become clear that the knowledge and skills with which students who obtained an NSC in 2008 entered HEIs were different from either the knowledge and skills that HEIs expect students to have or from those held by entering students in the past. This situation has highlighted the need for an in-depth look at school mathematics and science – the curricula, how they are taught, how they are assessed and how teachers are prepared to teach them – as well as the interface with science and mathematics at higher education level. In the process, issues related to transformation, equity and social justice will necessarily arise.

The Academy of Science of South Africa (ASSAf), as a body of natural and human scientists, has an important role to play in providing government and members of society with evidence-based information that can be used to influence policy and guide decisions for the benefit of society. The Science, Technology, Engineering and Mathematics (STEM) Education Committee of ASSAf has therefore organised this Forum at which participants will deliberate on critical issues in school mathematics and science education and make concrete proposals on how the situation can be improved. In particular, participants will consider three questions related to school mathematics and science:

- Where are we now?
- Where do we want to be?
- How do we get there?

Professor Robin Crewe

President: Academy of Science of South Africa

Chapter 1: Introduction

Diane Grayson

University of Pretoria

There is universal concern about performance in science, technology, engineering and mathematics (STEM) in South Africa. When South Africa participated in the Trends in International Mathematics and Science Study (TIMSS) in 1995, 1999 and 2003, we ranked last out of the 38 to 50 countries that participated. At university level, our graduation rates in STEM are poor. For the cohort of students who entered degree programmes at universities in 2000, 54% of engineering students and 44% of life and physical science students had graduated after five years (Scott, Yeld & Hendry, 2007). These figures, depressing as they are, are even more worrying when the overall participation rate of students in higher education is taken into account. In 2006 the participation rate, calculated as the percentage of students enrolled in higher education institutions relative to the population aged 20 to 24, was 15% (CHE, 2009). This figure is much lower than the figure for Latin America and the Caribbean (31%), Central Asia (25%) and East Asia and the Pacific (25%). Furthermore, in 2007 only 126 641 people graduated from public HEIs[1] with a higher education qualification, out of a total population of over 48 million people. In 2004 the ratio of registered engineers to total population in South Africa was 1:3166, compared to 1:543 for Malaysia, 1:227 for Brazil and 1:157 for India (Du Toit & Roodt, 2009). With figures such as these, it is impossible to provide the numbers of scientists, technologists and health professionals we need to provide quality of life to our own citizens, let alone to be internationally competitive. We are in a crisis.

The STEM Committee is a standing committee of ASSAf, chaired by Prof. Jill Adler. Like ASSAf itself, an important role of the STEM Committee is to monitor policy and make recommendations based on evidence and what Shulman (2004) calls “the wisdom of practice”. In planning this Forum, the STEM Committee thought long and hard about the contribution that ASSAf could make to addressing the crisis in STEM education. With ASSAf’s membership of eminent scholars in a wide range of fields to draw on, and given its relationship with HEIs, government and parastatals, the Committee believed that it was in a unique position to bring together a diverse group of stakeholders to discuss and debate not only the problems but also how to address them. The Committee identified five major topics for discussion:

1. *STEM and the National Senior Certificate.* How should the content of the Further Education and Training (FET) curriculum and the NSC be focused so as to best meet the needs of students who will follow diverse paths after they leave school?

2. *STEM teacher education.* What teacher education and professional development are needed in order to implement mathematics and science curricula at a sufficiently high level to enable South Africa and its students to become internationally competitive and locally effective?

[1] There are also graduates from private HEIs.

3. *STEM at the interface between school and higher education.* What is needed to achieve appropriate alignment between the FET band and higher education in order to facilitate success by academically able students at HEIs?

4. *STEM and the language of instruction.* What is the most effective way of teaching mathematics and science in a multilingual society?

5. *Evaluation and benchmarking of curricula.* How can robust tools be developed to benchmark the South African science and mathematics curricula and exit level examination papers against an external reference point?

For each of these topics, a speaker was invited to deliver a 45-minute research-based presentation. Participants were then given the chance to discuss the presentation and issues arising from it in buzz groups for 15 minutes, followed by a whole-group discussion for a further 45 minutes. The intention of the STEM Committee in using this format was to provide the opportunity for the concerns, suggestions, experience and wisdom of all participants to be shared. In these proceedings, we have therefore included not only the presentations but also a summary of the discussions. There was also an opening presentation by the Deputy Minister of Education, Mr Enver Surty, followed by presentations by three panel members and general discussion. In one session, participants divided into small groups to discuss the curricula of four learning areas, namely, life sciences, physical sciences, agricultural sciences and mathematics. A summary of these discussions is also included in the proceedings. Prof. Shirley Booth, an educator who is not a STEM specialist, was invited to be a critical observer. Her reflections form part of the proceedings. In Chapter 10 (Conclusion and Recommendations), a summary is provided of the main issues that emerged from the Forum, together with suggestions on how to move towards where we would like to be in terms of mathematics and science education at school level.

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Chapter 2: Setting the scene

WELCOME ADDRESS

Enver Surty

Deputy Minister of Basic Education

Programme director, members of the executive of the Academy of Science of South Africa, Chairperson of the ASSAf Forum, Prof. Diane Grayson, presidents of science councils, distinguished guests, ladies and gentlemen, 'good evening'.

Thank you for inviting me to the official opening of the ASSAf Forum. It is important that we debate and reflect on the critical issues that face us in mathematics, science and technology education in order that we may offer and act on relevant solutions. I believe that we have assembled at this meeting of the Forum because we share the common goal of promoting the advancement of quality education in our country, especially in the area of mathematics and science. This gathering has, in my view, brought together the finest scientific and enquiring minds in our country. I trust that we will use our collective wisdom to provide solutions to areas that pose challenges in mathematics and science education.

Our government has demonstrated a firm commitment to improving the quality of our education. To achieve this, we have committed to constructively engage with stakeholders in the sector to consider views that could contribute to advancing the goal of quality education for all. The importance of education to the new administration is demonstrated by the fact that government has deliberately created two departments, Basic Education (DBE) and Higher Education and Training (DHET). This is to ensure that we give more focused attention to each of the sections of our education system for improved quality. The Ministry of Basic Education focuses on mass literacy as well as primary and secondary school education. The Ministry of Higher Education and Training focuses on higher education, technical and vocational training. It will also take responsibility for the Sector Education and Training Authorities (SETAs). Both the ministries will continue to work closely together.

The ASSAf Forum is quite correctly concerned about the state of mathematics and science in our schools. Indeed, international assessments have demonstrated that our country's performance in these tests has been unsatisfactory. I therefore welcome the focus of this Forum on the three fundamental questions you have posed for the challenges that we face:

- Where are we now?
- Where do we want to be?
- How do we get there?

I will briefly reflect on some of the questions you have asked and offer further areas of thought for your deliberations during our conference.

In the 15 years of our democracy, there have been significant achievements and strides in education, especially with regard to access to education. We have achieved both universal primary education, in line with the Millennium Development Goals, and gender parity in education. More children are staying at school until grade 12, and over 85% of children are now receiving 12 years of education – either in schools or colleges. Our matriculation results have stabilised over the past few years despite a general consensus that the curriculum is far more demanding, and that the examinations have become much tougher.

One of the key areas that we must get right is the appropriate implementation of the curriculum and the comprehensive package of support that goes with it. In this regard, you may know that the Minister of Basic Education established a task team to conduct a consultative process with teachers and other stakeholders with respect to challenges in implementing the curriculum. The consultative process has been concluded, and a report on the findings is imminent. When the report is released, I would like to encourage you to consider its content and provide your objective assessment of what we may need to do to give impetus to addressing the challenges that we still face. The comments from the consultative process have indicated that an overwhelming majority of teachers and other stakeholders are satisfied with the curriculum (only two out of 500 written submissions called for the curriculum to be scrapped). There is thus general acceptance of and agreement with the high-level cognitive demands of the curriculum. However, there is a need to look at the obstacles that hamper the effective implementation of the curriculum. I am keen to remove such obstacles and allow teachers to focus on teaching, and learners to concentrate on learning.

What are some of these obstacles? Schools in poorer areas remain under-resourced. Science is being taught without laboratories, children share books and desks, and overcrowding continues in many of our schools. Some teachers are grappling with new content. Some teachers are unable to do practical work in physical sciences even when equipment is available due to a lack of exposure to practical work in their own schooling.

Qualified and committed teachers remain the mainstay of our system of education. The DBE is aware that the sustainability of our efforts in mathematics and science education depends on the availability of suitably qualified teachers. In the last three years, there has been a steady increase in the number of student teachers training in South African universities. In 2009 the numbers increased dramatically. In 2009, for the first time, we have been pleased to allocate direct grants to teacher unions to undertake development programmes for their members. This is in anticipation of a fully-fledged continuing professional teacher development (CPTD) system, to be managed by the professional council, the South African Council for Educators (SACE), which is being piloted in selected provinces this year.

The department has incentivised teacher training in mathematics and science. The Funza Lushaka bursary scheme was launched in 2007. The scheme provides full-cost bursaries that cover tuition, accommodation, a book allowance and a stipend to successful applicants. Approximately 9 000 students have received the bursaries, and approximately 2 000 of them will graduate and so be ready for placement in teaching posts in 2010. In the FET band, the largest number of bursary-holders is specialising in mathematics (1 225), followed by English language (907) and physical sciences (638). It is our view that by providing suitable conditions for support, we can build a strong foundation for the future development and sustainability of our education system.

The year 2009 marks the last year of the second phase (2005–2009) of the National Strategy for Mathematics, Science and Technology Education, which we originally launched in 2001. Given that this year is the last year of this targeted strategy, we will carry out an evaluation of the programme to establish the total impact of our interventions. This will assist the system to respond more appropriately to areas that still require dedicated attention in improving the quality of our education.

We have also noted good progress at the level of performance in mathematics and science in the Dinaledi schools. We have made progress with regard to the implementation of the objectives that we set ourselves in pursuit of a mathematically and scientifically literate society. Since the launch of the strategy, we have seen an increase in the level of participation. The attendance and performance of girl learners has also dramatically improved.

Notwithstanding the strides we have made, the challenges still remain daunting and will require an extraordinary effort by the department and all other stakeholders to ensure that we are able to enhance access to quality education for all.

There have been recent claims by HEIs that this year's first-year students are different from those of previous years, because the 2008 matriculation mathematics pass rate was 'exceptionally high'. They are reportedly failing to cope with their first-year studies in mathematics and are therefore not adequately prepared to cope with courses such as engineering, architecture and business science at tertiary institutions. It is important to the DBE that these claims be systematically measured and reported. If they remain anecdotal, then the DBE is not in a position to act to improve the curriculum, the examinations and teacher training. It is only with systematic and longitudinal evidence that we can act with you to address your concerns.

We invite ASSAf to offer practical and implementable solutions that we will consider as we move forward. Together we can do more.

Good luck in your deliberations!

Thank you.

Panel Presentation 1

EFFECT OF THE NATIONAL SENIOR CERTIFICATE AND OUTCOMES-BASED EDUCATION ON THE CIVIL ENGINEERING INDUSTRY IN SOUTH AFRICA

Elsabe P. Kearsley

University of Pretoria

Introduction

The mid-year pass rates for first-year engineering students dropped significantly between 2008 and 2009 (Serrao, 2009), with some universities reporting a 50% decrease in students passing. This paper aims to highlight the unintended consequences of the National Senior Certificate (NSC) mathematics curriculum and assessment.

National Curriculum Statement

In the National Curriculum Statement for Mathematics that was published in 2003, the following four learning outcomes were identified:

Learning outcome 1: Number and number relationships

Learning outcome 2: Functions and algebra

Learning outcome 3: Space, shape and measurement

Learning outcome 4: Data handling and probability

Although important concepts such as absolute values, the nature of roots, simplification of logarithms and inverse trigonometric functions (cosec, sec and cot) have been omitted from the curriculum, there does not seem to be any major problem with the curriculum in theory.

Results for 2008

The Department of Education states that 136 515 candidates passed mathematics and 207 260 passed mathematical literacy in the first National Senior Certificate examinations written in 2008. The number of candidates that passed mathematics with a final mark of more than 50% was 63 040. This number can be compared to the number of candidates that passed standard and higher grade mathematics in the recent past, as indicated in Table 1.

Table 1: Number of candidates passing mathematics

Year	Standard grade	Higher grade	Total
1996	59 614	22 416	82 030
1997	65 580	19 575	85 155
1998	68 315	20 130	88 445
1999	72 179	19 854	92 033
2000	79 631	19 327	98 958
2001	82 301	19 504	101 805
2002	96 302	20 528	116 830
2003	99 426	23 412	122 838
2004	109 664	24 143	133 807
2005	112 279	26 383	138 662
2006	110 452	25 217	135 669
2007	123 813	25 415	149 228

If it is assumed that an A symbol for standard grade mathematics is equivalent to a C symbol for higher grade mathematics, a significant number of candidates that passed standard grade (SG) mathematics in the past would have been able to pass higher grade (HG) mathematics. Penny Vinjevold (2009) used the information listed in Table 2 to motivate that the number of candidates that would have been able to pass HG mathematics in 2007 was 28 890 (comprising those that achieved A, B and C symbols for SG mathematics), which was more than the 25 415 indicated in Table 1. If the total number of 54 305 candidates for 2007 is compared to the 63 040 candidates for 2008, the results for the first NSC examination should not create concern.

Table 2: Number of candidates and symbols achieved in SG mathematics

SG Symbol	2006	2007
A	6 616	7 458
B	6 823	7 488
C	12 590	13 944
D	19 418	21 941
E	27 386	31 561

Mathematics assessment guidelines

The main concern with respect to the NSC is not the curriculum but the assessment as published in the Assessment Guidelines (DoE, 2008). The guidelines indicate that 55% of the questions in examination papers should require learners to use knowledge and routine procedures. Complex procedures should make up 30% of the questions and questions requiring problem-solving skills only 15% of the examination. This means that a student would be able to earn a distinction for mathematics through memorisation rather than problem-solving skills. The fact that candidates write examinations equipped with calculators as well as formula sheets (containing basic information such as formulae for the areas and volumes of basic shapes) makes it difficult to establish the actual level of students' understanding of the topics covered in the curriculum.

Mathematics paper 3 is not compulsory, and the geometry content of the curriculum is now examined only in paper 3. The non-compulsory content of the curriculum for grades 10, 11 and 12 is clearly indicated in Appendix A of the Assessment Guidelines (as copied in Table 3). The geometry curriculum content for grades 10, 11 and 12 is indicated as optional, and as the formal external mathematics assessment assesses only the Assessment Standards for grades 11 and 12, candidates that choose not to write paper 3 will have little, if any, knowledge of Euclidian geometry.

The Department of Education has been suggesting to universities that, especially for engineering, they should make paper 3 a part of their entrance criteria. The problem with this is that the majority of schools do not cover the work examined in paper 3 at all. Learners have to pay for extra tuition outside normal school hours. Of the 42 060 candidates that obtained 65% or more for mathematics in 2008, 64% did not write paper 3. There are unconfirmed indications that as few as 18% of the first-year engineering students at the University of Pretoria passed paper 3 in 2009.

Table 3: Extract from Subject Assessment Guidelines

APPENDIX 2: OPTIONAL MATHEMATICS ASSESSMENT STANDARDS FOR EXAMINATION IN GRADE 2 IN 2008, 2009 and 2010

Learning Outcome 1: Number and Number Relationships

When solving problems, the learner is able to recognise, describe, represent and work confidently with numbers and their relationships to estimate, calculate and check solutions.

Grade 10 We know this when the learner is able to:	Grade 11 We know this when the learner is able to:	Grade 12 We know this when the learner is able to:
		12.1.3 (d) Correctly interpret recursive formulae: (e.g. $T_{n+1} = T_n + T_{n-1}$)

Learning Outcome 2: Functions and Algebra

The learner is able to investigate, analyse, describe and represent a wide range of functions and solve related problems.

Grade 10 We know this when the learner is able to:	Grade 11 We know this when the learner is able to:	Grade 12 We know this when the learner is able to:

Learning Outcome 3: Space, Shape and Measurement

The learner is able to describe, represent, analyse and explain properties of shapes in 2-dimensional and 3-dimensional space with justification.

Grade 10 We know this when the learner is able to:	Grade 11 We know this when the learner is able to:	Grade 12 We know this when the learner is able to:
10.3.2 (a) Disprove false conjectures by producing counter-examples. (b) Investigate alternative definitions of various polygons (including the isosceles, equilateral and right-angled triangle, the kite, parallelogram, rectangle, rhombus and square).	11.3.2 (a) Investigate necessary and sufficient conditions for polygons to be similar. (b) Prove and use (accepting results established in earlier grades): • that a line drawn parallel to one side of a triangle divides the other two sides proportionally (the Mid-point Theorem as a special case of this theorem(; • that equiangular triangles are similar; • that triangles with sides in proportion are	12.3.2 (a) Accept the following as axioms: • results established in earlier grades • a tangent is perpendicular to the radius drawn at the point of contact with the circle, and then investigate and prove the theorems of the geometry of circles: • the line drawn from the centre of a circle, perpendicular to a chord, bisects the chord and its converse • the perpendiculr bisector of a chord passes

SUBJECT ASSESSMENT GUIDELINES: MATHEMATICS – JANUARY 2008

	similar; • the Pythagorean Theorem by similar triangles.	through the centre of the circle • the angle subtended by an art at the centre of a circle is double the size of the angle subtended by the same arc at the circle • angles subtended by a chord at the circle on the same same side of the chord are equal and its converse • the opposite angles of a cuclic aquadrilateral are supplementary and its converse • two tangents drawn to a circle from the same point outside the circle are equal in lenght • the angles between a tangent and a chord drawn to the point of contact of the chord, are equal to th eangles which the chord subtends in the alternate chord segments and its converse. (b) Use the theorems listed above to: • make and prove or disprove conjectures • prove riders.

Source: DoE (2008)

There is a perception that only engineers need or use the knowledge gained in learning outcome 3, but the unprecedented student numbers for 2008 in different CESM categories indicate that almost 100 000 learners need the knowledge gained in this learning outcome. This list excludes school-leavers that are not in tertiary education, and artisans should thus be added to this number. Any carpenter, builder, plumber, draughtsman, surveyor, welder and estimator uses Euclidian geometry daily, and in underdeveloped areas, knowledge of geometry provides people with basic life skills that they can use to build basic infrastructure.

The global recession

Manufacturers regard the low level of education and workforce skills as the biggest obstacle to investment. The International Monetary Fund stated in its 2008 *Country Re-*

port on South Africa that, "structural reforms would be required to improve productivity and employment growth" (IMF, 2008). The "ASGISA framework has already identified limited competition, skill shortages, and implementation capacity within government among the factors constraining growth. While efforts are being made to address these issues, much remains to be done". IMF staff stated that, "improving educational attainment is important for ensuring labour productivity gains in the long term. South Africa already spends comparatively generously on education", but "efforts need to focus on improving results within the existing budget and raising student achievement towards international standards".

The key challenge confronting authorities in employment creation is how to develop the tradable sector of the economy so as to absorb semi-skilled and unskilled workers to produce for export markets. This would help to reduce unemployment. School-leavers will be more employable and more productive once employed if they develop suitable skills while at school.

Solution

I have to agree with Marius Fransman (2009), the chairman of the Committee on Higher Education and Training in Parliament, that we need an education and skills revolution in South Africa. The Labour Force Survey of 2006 found that almost 50% of people in the age group 15 to 24 had no jobs and were not currently in the education system. Statistics South Africa stated that for the second quarter of 2009, 71.4% of 15- to 24-year-olds were economically inactive. Minister Blade Nzimande (Minister of Higher Education and Training) noted recently that about 2.8 million 18- to 24-year-old South Africans were neither employed nor in education or training. The aim of outcomes-based education was to provide the average school-leaver with the skills required to earn a living. In my mind, knowledge of geometry is an essential life skill and should be linked to practical applications to ensure that learners and teachers appreciate why and where theorems can be used.

Conclusion

Making geometry a non-compulsory part of the mathematics curriculum is totally unacceptable. The problem-solving thinking process that is developed through solving geometry problems is not only essential in developing innovative engineers and scientists, but it is my opinion that we are taking an important life skill from the learners by not linking geometry to applications used daily by all of us. We have to acknowledge that not all schools have the staff required to present the new curriculum, but currently the schools with qualified mathematics teachers are opting out of presenting the content of mathematics paper 3. In the short term, schools that have the capacity to present the full mathematics curriculum should not be given the opportunity to opt out, but schools should have to apply for permission not to present the work in paper 3, and the DBE should grant permission not to cover the non-compulsory part of the work only to schools that truly do not have the capacity to do so.

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Panel Presentation 2

Cassius Lubisi

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Very important issues were raised by the Deputy Minister if we want to improve the standard of mathematics and science teaching in the country, and important questions were added by Prof. Jansen. It is always important to correctly identify the problem if we are to act appropriately. Wrong treatment results from incorrect diagnosis. Why is there a credibility gap? Because people often respond from their own perspectives, which tend to be informed by their interests. Teachers and officials will give different accounts of the problems, and we have to establish the truth somewhere in between, because each is protecting their interests.

I would like to concur with the Deputy Minister that the teaching of mathematics and science in South Africa represents a crisis, no matter how you look at the situation, and there is no point in denying that. If we deny the existence of the crisis, we will not be able to solve it. We could have different understandings of what causes the crisis, but denialism is very dangerous. We are pleased that this Forum gives us an opportunity to talk about the issues in a non-threatening and safe atmosphere, where we can all speak the truth without fear.

The purpose of the symposium is not to throw stones at the government, but together to analyse the issues, and not simply end by prescribing the remedy, but actually do something about it. We sometimes get caught up in the syndrome of analysing *ad nauseum* but doing nothing about it. The point is not just to analyse the world but to change it.

Prof. Jansen raised the issue of whether we are looking only at problems in mathematics and science education or at more general system dysfunction. During debates on mathematics and science education in the early 1990s, there was a strong school of thought that focused on the urgency of teaching mathematics without being concerned about issues of social justice. Some of us objected strongly to that approach, because teaching and learning occur in a context, and it is not possible to separate the learners from the context in which they find themselves, nor can the teacher be separated from that context. While we are dealing with issues that are technical in nature, we cannot avoid the context-specific issues. If we are teaching children that come from poor backgrounds and are hungry, the evidence suggests that as a rule, no matter what teachers do, such children will perform badly for various reasons, including the lack of skilled teachers, the fact that the learners may not have eaten and that they do not have access to adults with knowledge to assist them with their homework. We did an analysis of grade 12 in schools in KwaZulu-Natal per quintile over the past few years. We looked at the correlation between the quintile position of the school on the poverty list and its success in mathematics, science and general pass rate.

We found a direct correlation in quintile 1 (the poorest sector). We anticipated this result, but were shocked that the relationship was so direct. It thus becomes a rule that for learners from the poorest districts, the likelihood of failing matriculation is great. There are thus certain contextual issues that one always has to deal with.

In KwaZulu-Natal, there is a district bordering Mozambique that is the worst performing in terms of matriculation results. The mathematics teacher cannot be readily distinguished from the learners because she matriculated at that school the previous year. When interrogated, the knowledge of mathematics of teachers in the district is shocking. There are thus effectively no mathematics teachers.

In 2008, the KwaZulu-Natal Department of Education advertised 4 900 posts, including mathematics and science teaching positions. Of these, 2 500 posts could not be filled because no suitable candidates could be found; 800 of the unfilled posts were for mathematics teachers. In some districts, there is an oversupply. However, teachers do not want to be posted to rural areas, because it is far more expensive to live in rural areas than in cities. In rural areas, there is no electricity and hence no fridge, so food must be bought every day; the price is higher because the food cannot be bought in bulk. Teachers do not want to be posted to rural areas. Some use the strategy of accepting a post in a rural area and leaving overnight if they are offered a post in an urban area. This is the reality of the context in which many of the schools find themselves. We will not succeed in encouraging teachers to go to the rural areas unless we address the material conditions in which they live. They will not go voluntarily. This is a broader societal issue that is not related specifically to mathematics or science education, but it impacts on what happens in mathematics and science classes.

It is regrettable that many of our schools are very dysfunctional, and these tend to be schools of the poor. The issues include lack of commitment by some teachers and officials, as well as lack of knowledge of how to manage a school. Even if a good teacher can be found and deployed in a rural area, there are other problems. For example, if a well-qualified Zimbabwean teacher is deployed, there may be initial resistance from the school, because the unqualified teacher that will be replaced may be the son or daughter of the local nduna, who objects to the job being given to a foreigner. It is then necessary to enter into negotiations. In any analysis of success, it is critical to use the school as the unit of analysis, rather than the individual teacher. The school has a particular culture, ways of operating and a history, which persist while individual teachers come and go.

Prof. Vijay Reddy of the Human Sciences Research Council (HSRC) did a regressional analysis to establish whether the school is a predictor of success. She found that in model C schools, there is a consistent correlation with performance, but in the case of previously disadvantaged schools (which are still disadvantaged), there is no consistent relationship that allows predictions of performance, which vary significantly from year to year. There thus appear to be problems with the school as a unit of analysis. There is anecdotal evidence that the efforts of the best teachers will be in vain if they are placed in a dysfunctional school, where there is no culture of teaching and learning, unless there is a critical mass of good teachers. In addressing issues of mathematics and science education, we have to address other aspects of the dysfunctional system at the same time.

The Deputy Minister referred to the Dinaledi schools. The national statistics to which he referred are similar when considering KwaZulu-Natal individually. Only 5% of the high schools in the province are Dinaledi schools, but they contribute over 20% to the mathematics and science passes. The findings of the study for the Roadmap Process (DBSA, 2008) were similar, in that 21% of schools contribute 80% of the passes in mathematics and science.

Addressing the problems only at grade 12 level is ‘too little, too late’, trying to salvage what has already gone wrong. In that regard, initiatives such as the Foundations for Learning campaign of the Department of Education say that while it remains an issue of human rights to assist and support grade 12 learners, it would be mistaken to consider that an appropriate strategy. The strategy should start at the bottom. It is a failing of South Africans to think only in the short term. We should think like the Chinese, who put in place 50-year plans. By comparison, South Africa changes its programme with each new administration. However, the results of the education process are not seen in the short term but much later. We should get to the point where we no longer need matriculation or first-year intervention programmes, because the problems throughout the education system have been rectified.

We tend to be scared of technology in this country, but should perhaps begin to consider how technology could be used to address the issues. Why not use technology to tap into the expertise of good teachers and broadcast lessons from the best teachers to schools in township and rural areas? A pilot project of that nature, linking St Albans with 25 schools in Mamelodi in Pretoria, yielded very positive results. In that way, we could start to address the shortages of teachers, since it is unlikely in the short term that teachers will be willing to be deployed to rural areas.

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Panel Presentation 3

SOME CRITICAL ISSUES IN SCHOOL MATHEMATICS AND SCIENCE IN SOUTH AFRICA

John Volmink

Cornerstone College

I like the thrust of what we have gathered to address at this symposium. I believe we need to ask ourselves another question – not only where we are, but where we have come from. Sometimes we forget that and then become too hard on ourselves. We have many hysterical voices in the media to which I do not wish to add. I believe that we have made steady progress, although it may not always appear so. We need to think soberly and consider the questions.

There is tension between where we are and where we want to be. None of us like to live with that tension. When we feel the tension for too long, we want to get rid of it, and the easiest way to do so is to give up on the vision. There is pressure from the media to abandon our education goals. I would like to believe that this Forum will look honestly, rather than defensively, at our current reality and decide how to proceed. That is another way of escaping the tension without becoming cynical and abandoning the vision. Cynicism arises when the objectives are so big as to be unattainable. We unfortunately see much of that in this country.

Some of the dashboard indicators for judging the quality of results include:

- the number of candidates passing;
- the quality of the results;
- the reliability of the predictive quality of the examination for performance at higher education level;
- the standard of the curriculum.

One of the problems is that we are driven by our metaphors, which highlight one way of looking at an issue and obscure other ways. Assumptions affect our perceptions, and we fail to interrogate them. One assumption that fuels scepticism is that 'more means less' or 'more means worse'.

With respect to the candidates writing and passing matriculation over the last decade:

- South Africa has seen a steady increase over the last decade in the number of learners who enrolled for and wrote the NSC.

- Massification is a natural outcome of an education system that is non-racist, non-sexist and democratic.
- The underlying philosophy of the National Curriculum Statement (NCS) is that it has been designed to ensure that most learners achieve the minimum requirement for a pass.

My view is that the 2008 NSC examination was harder for those at the bottom than in previous years, and softer for those at the top. Any problems with the examination can be fixed, and do not mean that there are necessarily problems with the curriculum. The Senior Certificate pass rates (1994–2008) illustrate the mathematics of large numbers, in that things progress slowly. In 1994, 52% of candidates passed the matriculation examination. That is not a crisis. If we talk of a crisis, we need to define what we mean.

There has been a long-standing debate on whether the school-leaving results are good predictors. It would be interesting to see how third-year students performed in the National Benchmarking Test; we might have found little difference between the first-years and the third-years, since there are many factors at play beyond the 2008 NSC examination.

Predictive quality of NSC results

Historically, matriculation marks were reasonable predictors for white South Africans but less so for black South Africans. It is impossible to be definitive about the predictive quality of the NCS after the first year of its implementation.

Implications of the 2008 NSC results for higher education

The 2008 NSC examination was possibly harder for those at the bottom and softer for those at the top. We need additional information to discriminate at the top end. However, most candidates with a B pass in the NSC would have equivalency with respect to cognitive demand and content knowledge with a Senior Certificate candidate who obtained an exemption pass in 2007. The NSC candidate also brings additional knowledge, values, skills and attitudes.

The NSC philosophy

The National Curriculum Statement represents a different set of standards for all – not higher or lower, just different. It reflects the new values embedded in the Constitution. It also aims to develop learners who can respond to the growth and development of knowledge and technology and the demands of the 21st century. The curriculum is grounded in the Constitution, but in assessment, we look only at the outward manifestation of that thinking.

The case of mathematics

Mathematics is constantly singled out in discussions on curriculum reform and examination results. We tend to forget that historically, 30–40% of secondary schools in the country simply did not offer any mathematics at all beyond grade 9. In 2008, all 590 000 matriculation candidates took some form of mathematics (either mathematics or mathematical literacy). We are embracing the complexity of the system in its entirety for the first time.

Mathematics and the class of 2008

The class of 2008 had 63 038 learners who passed mathematics at the 50% level or higher. This stands in contrast to the 25 000 who passed higher grade mathematics in 2007. A further 207 230 learners passed mathematical literacy in 2008, most of whom would not have done any mathematics in the previous system. A total of 16 557 passed mathematical literacy at the level of 80% or higher.

Strategy to increase learner achievement

The key challenge is not so much to explain and to tell, but to inspire and affirm learners to engage with the subject and to include mathematical and scientific proficiency as part of a ‘possible self’. One of the ironic gifts of apartheid was that talented people, who under a different system could have gone into many different professions, were virtually forced to become teachers, and they inspired, affirmed and changed the generations of pupils that they taught. I believe that learners have to commit extra time to the task. I also believe in the provision of high-quality learning resources.

Basic indicators of quality in mathematics teaching

The quality of mathematical teaching depends on whether the teacher can:

- selectively use cognitively demanding tasks;
- plan the lesson by elaborating the mathematics that the learners must learn through those tasks;
- allocate sufficient time for the learners to engage in and spend time on the tasks.

Five strands of mathematical proficiency

Jeremy Kilpatrick *et al.* (2001) talked of:

- conceptual understanding: comprehension of mathematical concepts, operations, and relations;

- procedural fluency: skill in carrying out procedures flexibly, accurately, efficiently, and appropriately;
- strategic competence: ability to formulate, represent and solve mathematical problems;
- adaptive reasoning: capacity for logical thought, reflection, explanation and justification;
- productive disposition: habitual inclination to see mathematics as sensible, useful and worthwhile, coupled with a belief in diligence and one's own efficacy.

These are skills in mathematics that we should get our learners to aspire to.

Professional development of teachers

Effective teachers of mathematics have high expectations for all their learners and inspire learners to value learning activities. They can interact with learners of different backgrounds and abilities and establish communities of learners.

First stage of professional development of teachers

In a professional development programme for teachers, they will be assisted in context with:

- meticulous planning and preparation based on strong subject knowledge;
- the logical and systematic construction of a lesson;
- core teaching skills such as questioning, exposition and illustration;
- the personal power, presence and leadership of the teacher;
- an understanding of the different modes of interaction between the teacher and the learner;
- participation in a community of practice.

Our focus in professional development programmes for teachers is wrong. We focus on teachers rather than on teaching. We should avoid simply applauding the few good teachers and rather focus on changing standard practice. Is a good teacher one that draws applause or one that networks with people and acts as a seed carrier of the new culture, working within the community of learners? We have to change the focus from 'teachers' to 'teaching' and professionalise teaching rather than teachers.

Fullan and Hargreaves (1992) point out that:

> … educational conservatism is sustained by uncertainty, isolation and individualism. When teachers are afraid to share ideas and successes for fear that others might

steal these ideas or alternatively that they may be perceived as blowing their own horns, we have reached a point where the school has institutionalised conservatism.

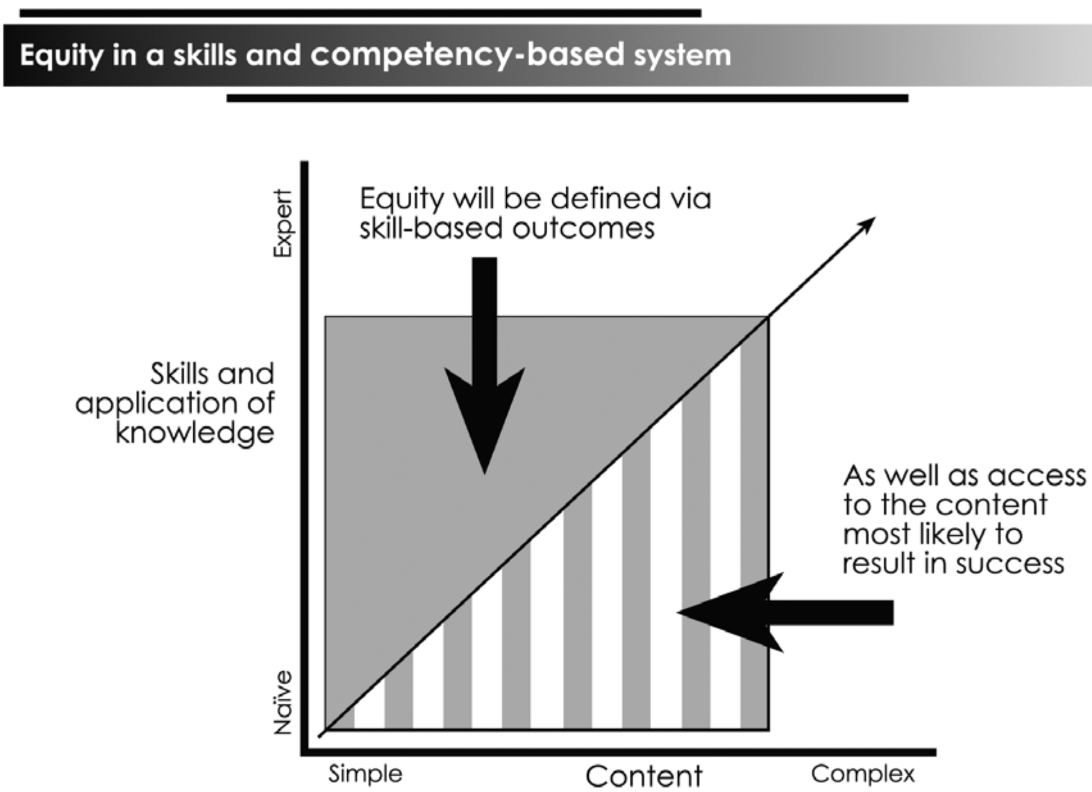
They point to the need to "crack the walls of privatism" in our schools if we are to create good schools.

John Tanner poses the question of what an educated person constitutes. The basic model proposes that the more time you spend at school, the more educated you become. The focus in that model is on the content axis. When a student tests well on a body of content, we use that as a proxy and assume that the student has also mastered a set of skills. Only the content gap is exposed and receives attention.

In a proficiency-based system, with a focus on skills, we consider what content is needed for the skills and proficiency we are seeking to develop. An outcomes-based education system, by its very nature, is not supposed to be input-based, yet everything we do, negates that. We continue to look at the content input rather than the skills. We demand that teachers teach more content better than they did before in the hope that the necessary skills will emerge, which is unlikely. With access to IT, for example, content arises from skills in accessing it.

Equity in that context must relate not only to skills that we acquire but also to access to content most likely to result in success (Figure 1).

Figure 1: Equity in a skills and competency-based system



Let us keep our goals in mind, namely, to develop a system that looks at both skills and applications, as well as content.

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DISCUSSION

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The discussion following Basic Education Deputy Minister Mr Enver Surty's welcome address and the panel presentations of Prof. Elsabe Kearsley, Dr Cass Lubisi and Prof. John Volmink focused on the National Curriculum and particularly on the optional nature of paper 3 in mathematics and the varying interpretations of the role of geometry in the curriculum. There were also comments on consultation with respect to national curriculum decisions, and suggestions that given the diversity across the academies, ASSAf could and should present the important voice of the Academy with respect to the school curriculum. The panel was chaired by Prof. Jonathan Jansen. In the summary that follows, comments from the floor are captured and grouped. Responses from the panel and panel chair are also included.

The consultation or communication process with respect to the National Curriculum

The discussion was opened by Penny Vinjevold, then Deputy Director-General of Basic Education, with a chronology of events related to consultation with universities and academics on the National Curriculum indicating various and numerous communications between the department and universities. After noting that the department was aware of the problems with the mathematics paper at both ends (too difficult at the lower end, and not challenging enough for high attainers), Ms Vinjevold specifically drew attention to the department's suggestion to universities that they make paper 3 a requirement for entrance to certain degrees and faculties, and invited ASSAf through this Forum to inform the department of concerns.

Later in the discussion, Dr Lubisi also challenged perceptions around consultation and communication before the implementation of the curriculum. He stated:

> I was the chairperson of the ministerial committee that developed the NCS for FET. There were over 250 writers organised into working groups, each of which was drawn from a variety of sources, including universities and schools. There was a reference group that met monthly throughout the process to consider each document that was produced. When the first draft was released on 22 October 2003, it had already been widely consulted. We received large numbers of written submissions. We adopted a strategy of taking the writing team around the country to meet in different centres. Wherever the team met, we called a meeting of local specialists in the various subjects to critique the work. There was thus massive consultation.

Optional paper 3 in mathematics

The highlighting of the optional nature of paper 3 by Ms Vinjevold's comments, and the consequences for engineering in particular in universities discussed by the panel, provoked lengthy discussion on what had been 'lost' by placing Euclidean geometry in the optional paper. In addition to questions as to where responsibility lay for addressing this new 'gap' between school and university, there were comments on the problems that came with optional aspects in a national curriculum. There were also concerns expressed that 'geometry' was discussed somewhat 'glibly', and that more careful consideration was required. Key comments are captured below:

> Euclidean geometry is concerned with proof; it is not about understanding space and shape. We do not need a plumber to be able to prove a theorem, but to have a good idea of space and shape. We should be careful when we talk glibly about needing Euclidean geometry. There could still be significant geometry in the NCS, but this was not played out in the examination assessment. We should be careful about calling for the return to the curriculum of a large quantity of rote-learned proof. We should think carefully about the kind of geometry and geometrical understanding that we want back. The National Curriculum (Vocational) (NCV) contains a long list of theorems and proof, which are probably not appropriate or necessary for those planning a career as an artisan.
>
> ... I am concerned whether we clearly understand what we have lost. In the past, high school mathematics pupils got most of their problem-solving experience in geometry. Perhaps the loss of Euclidean geometry goes beyond the loss of geometry itself, and there has been a loss of something else that now needs to be replaced.
>
> Anything in a curriculum that is optional causes confusion; first among teachers and schools, who consider how they can best make use of the optional component. Those that wish to maintain high marks simply cut it out in order to do so. It has also thrown the universities into confusion, for the very reasons suggested. In our attempt to meet the transformation agenda, we have been forced to rule that mathematics paper 3 is not compulsory, because the schools that are least likely to be able to offer tuition for mathematics paper 3 are the very poorest of the schools.
>
> For the first time this year, we have had to make the intervention of presenting a six-week course in geometry for first-year students, which they thoroughly enjoyed. They were able to master the course. One would wish, however, that students are taught geometry at school before they come to university.

Prof. Volmink responded that there was no intention to eliminate geometry from the curriculum, but given current realities, it was considered unfair to hold everyone in the country accountable to the same content. The idea was that within a reasonable period of time (about four years) all schools would be in a position to teach the whole curriculum, but in the meantime, the core curriculum would be offered until the necessary teacher training and development had been completed. As is now known, this too became a point of contention and the whole curriculum is under review.

Prof. Jansen, in summing up the discussion at this point, noted that there is a real problem in the connection between what learners learn at school and what they are expected to learn at university, and that ASSAf is clearly in a position to advise on that issue.

Prof. Kearsley, the panellist who drew attention to the issue, clarified that her comments were not a proposal to return to the old curriculum; rather her concern, "relates to the examination of the curriculum. There are essentially two aspects to Euclidean geometry: (1) proof, and (2) applying one's knowledge to solving the problem. We seem to be lacking the thinking process associated with problem-solving." She also expressed the concern that schools that in the past achieved 100% pass rates had chosen not to offer tuition for mathematics paper 3, thus reinforcing the comment made from the floor that the optional nature of the paper had unintended effects. "We thus seem to be moving the wrong way. We should be giving the poorly resourced and equipped schools the chance to prepare themselves to offer mathematics paper 3", she said. "We did a survey among the approximately 1 700 first-year engineering students at the University of Pretoria this year to establish how many of them had written mathematics paper 3 and found that only 18% had done so. Euclidean geometry is a critical scarce skill. If the university insisted that learners only be admitted to engineering if they had written mathematics paper 3, and we were able to admit only 18% of our current first-year class, we would be doing the country a disservice."

Additional comments related to the poor emphasis on skills in the curriculum, as well as the question of where the responsibility of preparation for university lay.

Prof. Jansen closed the discussion by referring again to the role of ASSAf in taking the conversation forward.

Chapter 3: STEM and the National Senior Certificate

SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS EDUCATION AND THE NATIONAL SENIOR CERTIFICATE IN SOUTH AFRICA

Lebs Mphahlele[2]

Palama

Introduction

The founding conference of the STEM (Science, Technology, Engineering and Mathematics) Forum of ASSAf tabled a number of critical issues on school mathematics and science. One of these issues relates to how the content of the (FET) curriculum and the National Senior Certificate (NSC) should be focused so as to best meet the needs of students who will follow diverse paths after they leave school.

This content issue was unpacked into the following seven questions, to which I was requested to respond:

- What was the purpose of the NSC when it was first proposed?
- Has it changed?
- What unintended consequences have resulted from the way in which the NSC has been implemented?
- What should be done differently in the future and how do we do it?
- What should the purpose of the NSC be in future?
- What are the issues around mathematics and mathematical literacy in terms of content and making them compulsory?
- Should there also be an equivalent compulsory subject for the sciences, namely science literacy (as was originally proposed)?

In responding to these questions, ASSAf advised that I consider the following three questions related to school mathematics and science:

- Where are we now?

2 The views expressed in this paper are personal and do not represent an official position of government.

- Where do we want to be?
- How do we get there?

Responses to these questions will largely be informed by my personal experience as a participant in almost all the curriculum change iterations of the post-1990 policy landscape. I will view the questions as a preconceived lens through which to analyse delivery of post-apartheid curriculum policies in general and the implementation of the NSC during its first year in 2008.

While reflecting on my own experiences, I take cognisance of the unprecedented strides made to ensure that curriculum policy-formulation processes are both representative and participatory. I also acknowledge the adoption of policies that promote universal access to science, technology and mathematics, at least in the first ten years of compulsory schooling. While heralded as a progressive policy step, this led many a critic to raise the following questions: Will standards drop? Will South Africa be less competitive in the world economy? Will there be speedy replacement of the largely aging, male and white scientists, researchers, engineers and technologists? Put differently, will increased access not lower quality? Will increased access not lessen success in areas in which South Africa has performed well? Will the inclusion of the historically disadvantaged in the mainstream discourses not negatively affect progress and development?

These are important questions, the responses to which will shed light on ‘concerns’ raised about the quality of the new NSC. The responses to these questions can only be understood within the context of fundamental curriculum policy changes that took place in the last decade.

Key curriculum policy changes

STEM curricula

The design features and principles underpinning the new science, mathematics and technology curricula are ‘innovations’ that have immense implications for teaching and learning in general, and assessment in particular. Whereas the old syllabi emphasised knowledge and rote learning, the new curriculum statements promote the application of knowledge and creative thinking.

There is, however, a concern that the skills-laden and values-laden learning outcomes might remain excellent features on paper but find little attention where it matters most, in the classroom. Key challenges and important milestones were achieved in the implementation of the new STEM curricula. While developing the new STM (science, technology and mathematics) subject statements, the emerging single system of education was showing signs of strain. This was evident in the decline in both participation and performance in mathematics and science during the period 1996–2000 (DoE, 2001a).

To arrest this decline, the Department of Education (2001b) implemented the National Strategy for Mathematics, Science and Technology Education (NSMSTE) with effect from 2001. Using, among others, dedicated schools as one of its targeted interventions, the strategy succeeded in improving both participation and performance in mathematics and science. More importantly, historically disadvantaged learners have been showing tremendous improvement in both enrolments and performance.

Since the signing of the Collaboration Agreement by the Departments of Education, and Science and Technology, the participation of institutions and professional bodies in supporting the delivery of the science and mathematics curricula has increased. Consequently, the target of doubling performance in both mathematics and science by 2008 was achieved.

Role of assessment

What does this mean for the NSC? Given the historic 'funnel' role played by the Senior Certificate (commonly referred to as 'matric'), the design and development of the National Curriculum Statement (NCS) Grades 10–12 (Schools) was particularly contested. It was not clear if the outcome of the development process would maintain the historic funnel role or not. The National Senior Certificate (NSC), previously known as the Further Education and Training Certificate (FETC), replaced the Senior Certificate with effect from 2008 and was phased in starting with grade 10 in 2006 (Department of Education website, as at 30 March 2010).

This begs the question: What is the difference between the Senior Certificate (SC) and the National Senior Certificate (NSC)? The difference is at conceptual, political-ideological and operational levels. While the emphasis on differentiated assessments formed the basis for requirements for university entrance (Trumpelmann, 1991), the NSC has a broader purpose that has implications for the *status quo*. The removal of vertical differentiation in the NSC challenged higher education institutions (HEIs) to rethink their entrance requirements. The school/HEI disjuncture brought into sharp focus the misalignment between the new school curricula and HEI curricula. At a conceptual level, the SC operated within a content-based structure, while the NSC operates within an outcomes-based system. While the former is driven by how much one knows, the latter is driven by how one can use 'content' to attain the set standards, the attainment of which leads to the achievement of the set outcomes. At a political-ideological level, the shift centres around the broadening of access to the historically excluded and the increasing throughput rates in these subjects. However, both the SC and NSC are certificates. They are awarded to those who satisfy the syllabus/curriculum requirements. Simply put, they are a form of recognition for performance.

The NSC policy has, by default, elevated the debate about the role of assessment in curricula. In the NCS, assessment is not just an isolated activity at the end of a learning process but an integral part of it. Its design has dual purposes: formative and summative (DoE, 2002 and 2003). The NSC is a registered qualification on NQF (National Qualifications Framework) level 4 and "provides the requirements for promotion at the end of grades 10 and 11 and the awarding of the National Senior Certificate at the end of grade 12" (DoE, 2003). It replaces the following two documents of the original NCS Grades 10–12 (General): the *Overview* and the *Qualifications and Assessment Policy Framework*. The NSC is "awarded for the achievement of the exit level learning outcomes stipulated in the National Curriculum Statement (NCS) Grades 10–12 (General)"

(DoE, 2005). In terms of the policy, the NSC qualification is "intended to provide qualifying learners with applied competence and a basis for further learning".

Historically, the focus has been on assessment tasks that were mainly used for summative purposes, like the proverbial tail wagging the dog. The new assessment regime has introduced a policy shift by introducing assessment for formative purposes. The ratio between summative (labelled end-of-year or external) and formative (labelled continuous) assessment in the NCS Grades 10–12 (General) for General Subjects is 75:25 respectively. Grades 10 and 11 assessments comprise 25% internal assessment, completed during the school year, and the end-of-year assessment mark, which makes up 75% of the total mark. The assessment of life orientation and practical subjects is structured differently, with the following breakdown: 50% for the end-of-year examination, 25% for continuous assessment and 25% for the practical component.

In more 'developed' systems, the ratio between formative and summative assessment ratio is heavily tilted towards assessment for formative purposes.[3] The arguments advanced for South Africa's arrangement are mainly capacity and resource arguments. Unless assessor capacity is developed at classroom, school and district levels, public confidence in the assessment system will remain low. As the system matures, the balance between formative and summative assessments will be achieved. Public confidence in the new system will also grow.

The challenge for assessment lies in the ability of practitioners and those in charge of providing professional support to schools to construct instruments to reliably assess learning in an education system that uses an outcomes-based approach. In such a system, learners are expected to be given an opportunity to learn at their own pace and to ensure that each learner's potential and talent are nourished and allowed to flourish. Such an approach has implications for assessment, more specifically assessment instrument design and construction. Therefore, there will be greater need for provincial and district offices to support educator professional development in the area of assessment.

To allow all learners to succeed necessitates individualised and collective methods of assessment. This requires all practitioners to be assessors in an outcomes-based sense. This poses challenges of validity and reliability (Taylor, Muller & Vinjevold, 2003). Such challenges include:

- Languages of the instrument: many assessment instruments in South Africa for science, mathematics and technology are written in English/Afrikaans.
- What to assess: the curriculum statements specify minimum content and contexts required to attain assessment standards. This arrangement makes room for local input of content and the use of local contexts. How does one derive a universal statement about results from such a performance?
- Length of instruments: very often assessment instruments are time-bound.

There will be a need to explore practical strategies within the outcomes-based approach to education and training in order to address issues of the validity and reliability

[3] See European experience in papers presented at the ASSAf conference.

of assessment. The key advantage of the new curriculum using an outcomes-based approach is that it promotes a multiplicity of ways to assess learning.

Mathematical and science literacy

The intention of the new curriculum is to ensure that all learners leaving the schooling system are mathematically literate. While mathematical literacy is a subject on its own, this does not, in any way, imply that the subject of mathematics does not promote *mathematical literacy*. The converse is true.

From a policy point of view, mathematical literacy is enforced through a fundamental component of the NSC in which all learners are expected to register for either mathematics or mathematical literacy. This is unprecedented given South Africa's history of discrimination and exclusion, especially in the fields of mathematical sciences.

While all learners in the General Education and Training (GET) band (i.e. grades R–9) have universal access to the natural sciences, no science subject is compulsory for all learners in the Further Education and Training (FET) band. The natural sciences learning area – and the subjects, physical sciences, life sciences and agricultural sciences – promote science and scientific literacies through activities aimed at achieving, especially, values-laden learning outcomes. The nomenclature used for the science subjects uses plural names to demonstrate philosophical departure from the exclusivist approach of the previous dispensation. This conceptual shift promotes epistemological inclusivity and integration of the principles underpinning the NCS.

Unlike mathematical literacy, science literacy is promoted through a multiplicity of interventions. The Collaboration Agreement signed by the Departments of Science and Technology (DST) and Education in 2004 allocates the responsibility for promoting science literacy to the DST, hence the promotion of science and technology literacy as one of the two goals of the DST's Youth into Science Strategy (DST, 2006). Exploiting its network of science centres, the DST seeks to use this infrastructure to promote STEM awareness campaigns in both the education and science systems.

In addition to these factors, the resource and capacity constraints dictate that a distinct science literacy subject for all learners would pose a serious challenge in a system that is already over-stretched by the introduction of new curricula and qualifications. Given the high status assigned to these 'gateway' subjects,[4] complex administration of examinations in under-resourced educational environments could have negative results.

However, national debates on the need to give attention to, among others, 'middle subjects' for both mathematics and science rages on. The Historic Schools Restoration Project[5] (HSRP), for example, initiated a dialogue on the need to restore the dignity of

[4] They are also described as priority and/or scarce in ASGISA and other key policy documents.

[5] The Historic Schools Restoration Project was established by government to restore schools that produced many of the leaders of today. It is funded mainly by the Department of Arts and Culture with the Departments of Basic Education and Science and Technology supporting its implementation in various forms. Its champion is Archbishop Ndungane.

some of the schools that played an important role in producing leaders in various sectors of society. One of its proposals is the possibility of having 'third-tier schools'. These are schools which the Department of Basic Education would adopt, resource and administer at national level. While the debate rages, the equity and redress issues have yet to be satisfactorily addressed. ASSAf might well engage with the gist of HSRP's arguments with a view to formulating a proposal on this institutional arrangement for mathematics and science.

The fact of the matter is that the strategies for mathematics, science and technology adopted thus far seem to be bearing fruit (see details of the performance of these strategies in the keynote speech given by the Deputy Minister of Basic Education at the ASSAf conference). The disturbing development, however, is the steep increase in unemployed science, technology, engineering and mathematics (STEM) graduates, most of whom are historically disadvantaged. Although the DST, through its Youth into Science Strategy, is addressing this rising unemployment among STEM graduates through its National Youth Service and Internships, the effort can only be remedial. A more systemic and well-coordinated national effort is required, which means ensuring that the education, science and innovation systems work in tandem. This is urgently needed given the benefits of the science and mathematical literacy campaigns that are beginning to demystify these subjects/disciplines.

Critical issues

The following critical issues emerge from my personal reflection on STEM curriculum policies and practice.

Access and/or success

Access to science, technology, engineering and mathematics (STEM) is one of the principles of the new curriculum statements. Access refers not only to increased enrolments but also to epistemological access. The standards used cannot continue to be those inherited from the unequal past but must bring into the mainstream the historically excluded knowledge systems. Broadening access to science and mathematics leads many to question the quality and, therefore, the ability of the new system to succeed in breeding the best scientists, engineers and technologists of 'international standard'. The temptation is to address perceived low quality of 'outputs' by tinkering with the 'examination papers' to ensure that they continue to be of 'acceptable standards'. Such an approach continues to view the NSC with the eyes of the old Senior Certificate. It does not view the NSC as a qualification for the whole FET band. ASSAf is well advised to analyse and view the NSC as a continuum in the whole band and not an activity at the end of 12 years of schooling.

Quantity and/or quality

The new National Curriculum Statements for the schooling system promote universal access to STM in the GET band and universal access to 'mathematical sciences' in the FET band. This policy position addresses one of the historically debilitating bottlenecks of the pre-1994 education system. The consequence of this policy, it is assumed, will lead to poor-quality outputs. The issue is: Are higher education institutions ready to receive the new type of learner who will emerge from the new curricula with their design features and principles covering areas that even higher education institutions are not competent to cover? This is another area ASSAf may well analyse and investigate in order to shed more insights that the education, science and innovation systems may take heed of. The task becomes even more vital considering the mandate of the NSC to be broader than just channelling high school learners to higher education institutions. Thus the quantity/quality debate, like the access/success debate, also needs ASSAf's attention.

Once-off, high stakes

The 'once-off, high stakes' NSC examination attracts national attention like no other ritual. The government's focus on performance in grades 3, 6, 9 and 12 is an attempt to identify and remedy shortcomings early in the schooling system. The intention must be to build capacities to promote the formative role of assessment in all pockets of the schooling system. The challenges of validity and reliability will have to be addressed by strategies whose main purpose will be to build these capacities. While this task will take a long time to materialise, it is in the best interests of society for ASSAf to assist in providing insights on models and practices that have the potential to build robust and sustainable assessment regimes that will slowly move away from 'once-off, high stakes' examinations.

Systemic education change

While the aim of this short paper is to provide responses to questions posed about the nature and future of the NSC, it is important to mention the futility of focusing on the qualification without viewing it as an integral part of the National Curriculum Statement Grades 10-12 (General). The Department of Basic Education understood the systemic nature of the curriculum policy by developing Learning Programme Guidelines per subject and the NSC which, as demonstrated earlier in this short paper, replace the *Overview* and the *Qualifications and Assessment Policy Framework* of the NCS. ASSAf, in advising on the implementation or review of the NSC, is advised to establish the relationships between the qualification, curriculum policy, assessment, teaching and learning, support materials and professional support given to practitioners.

Talent and potential

Government has developed STEM strategies with the main purposes not only of promoting these fields but also identifying and nurturing talent and potential. Given the upward trend of unemployed STEM graduates, the majority of whom are from disadvantaged backgrounds and institutions, there is a need to link teaching, learning, employment and livelihood. This would require ASSAf to introduce the role of STEM in promoting notions of 'talent and potential', 'innovation' and 'livelihoods' in conversations related to participation and performance in STEM. That would require ASSAf to be 'innovative' in the way it investigates and reports on these notions.

Institutionalised systemic reviews

Systemic change takes a long time. As demonstrated in literature on change (Fullan, 1992; Hargreaves, 1998), systemic change entails doing the right things and doing things right consistently and persistently over a period of time. To detect early warning signs, it is important to conduct regular reviews; every five years is a standard and co-incides with political time-tables. Institutionalisation of such reviews will stabilise the system and allow 'innovations' to take root prior to evaluating their impact or lack thereof.

The future

The finger of the academics is usually pointed outward at the NSC and less so inwardly. It is time that, on the one hand, the roles of higher education/school curricula are aligned and, on the other hand, that the links between the education system and the innovation system are strengthened. ASSAf could well use evidence-based research to shed light on these interrelated issues.

Concluding remarks

Where are we now?

The foreword of the proceedings of this ASSAf Forum meeting (ASSAf, 2010) acknowledges that the new NSC "succeeded in releasing what was a considerable blockage to entry into higher education", but raises "concerns about the 'capabilities of school-leavers' as compared with those of a decade ago". "Early indications are that overall student performance in science-based programmes at higher education institutions is below that of previous years", it adds. By implication, the decline in performance of science students will severely limit the creation of a future pool of "potential scientists, engineers and health practitioners, as well as future teachers of mathematics and science".

The disjuncture between higher education and school curricula requires urgent attention. Universal access to STEM in the schooling system has begun to 'produce' more learners than the higher education system can accommodate. This state of affairs will challenge the whole education system, not just some pockets, to 'modernise' and adapt to new conditions brought about by the post-apartheid order. The NSC, as a qualification, will need to be aligned to qualifications in the higher education system and occupational pathways.

Where do we want to be?

The assessment regime will need to slowly tilt towards making formative assessment more credible and weightier than summative assessment. This will necessitate new capacities to be developed in policy-making institutions, research institutions, schools, education districts, training institutions, support materials industries and quality assurance bodies. Such an assessment regime should be sophisticated enough to assess learning as expected in the National Curriculum Statement. Future systems could, for example, develop assessment instruments that are valid and reliable to assess scientific investigations and the use of indigenous knowledge systems in science or mathematics classrooms.

How do we get there?

The strengths of various institutions, departments and organisations need to be part of national efforts to develop a new assessment regime. For example, the Department of Science and Technology established a National Indigenous Knowledge Systems Office (NIKSO) with responsibility, among other things, for creating a 'laboratory' of indigenous knowledge systems. Collaboration between NIKSO and HEIs, for example, could well formulate ways of designing credible instruments to assess learning IKS in STEM curricula. The Country Strategy on Human Resource Development (DoE, 2009) provides a framework and coordinating structure to lead such efforts. An incremental approach will need to be adopted in implementing the strategy. Such an approach will need to be given time to take root before it can be reviewed. It is when support for 'innovations' and systemic change efforts of this nature are sustained that systemic change will begin to bear fruit for all of society.

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DISCUSSION

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Delegates had an extensive discussion on the purpose of the NSC, building on the position elaborated by the speaker. The view was expressed that although the NSC has a stated purpose of preparing learners for citizenship, it is still focused towards higher education. One delegate noted that only 5–10% of learners enrol in higher education institutions. Another delegate suggested that this, however, should not be considered an adequate participation rate, and that South Africa should be planning to increase participation in higher education. Nonetheless, the speaker reiterated the purpose of the new NSC:

> The question of the purpose of the NSC and whether it is only to prepare learners for higher education or also to prepare them for life and citizenship must be understood historically. Over the last three decades, universities would decide what should be taught and assessed in schools. The Matriculation Board was an office of the Committee of University Principals (CUP), which became the South African Universities Vice-Chancellors Association and then HESA. We need to understand that schools were geared to produce for the universities. As the country democratised, old roles, responsibilities and institutional arrangements were challenged. Some institutions were reviewed and relocated to the universities, including colleges of education and colleges of agriculture. However, the curriculum is intended for citizenship.

If the NSC is not geared solely towards higher education, then the question remains of the extent to which performance in the NSC should be considered a predictor of success in higher education. A delegate pointed out that passing the NSC does not necessarily mean that a learner will succeed at a higher education institution. What should universities do with respect to receiving learners when there are curriculum changes at schools? The subject content and skills with which learners enrol for higher education differ from before, particularly for those entering engineering studies. Do universities wait passively, or do they need to modify their courses to fit what learners bring into higher education and to receive the learners? What should universities do in terms of their readiness and preparedness to accommodate learners with different sets of skills? On these key issues, the speaker offered this view:

> On the issue of what universities should do in terms of preparing themselves to receive the new cohort of matriculants, I support the suggestion that there have been developments related to the school curriculum but not university curricula. I support the notion that institutions need to look at ways of responding to curriculum changes. Higher education institutions also need to focus on positioning themselves so that they avoid producing so many unemployed graduates. We need to take a systemic approach to the education system as a whole.

Extending the discussion on the purposes of the NSC, one delegate noted that:

> The point is made that the purpose of the NSC is to prepare people both for citizenship and for higher education. It should also prepare them for personal development as well as utility, in order to be a contributing worker. The NSC therefore is meant to fulfil at least four purposes.

Another delegate noted that we should not forget the 2.8 million youth between the ages of 16 and 24 that are neither working nor studying.

With respect to the massification of mathematics and mathematical literacy, a delegate noted that the country has taken a giant step in making it compulsory for all learners to take one of these two subjects, whereas previously not all high schools taught mathematics. What are the implications in terms of the demand for, and supply of, teachers for these subjects? In the past, many of the schools that taught mathematics did not do so at higher grade level. Is the country able to supply so many mathematics educators at one time? The speaker responded:

> The issue of massification is not related only to mathematical literacy. Because of democracy, the historically excluded are becoming part of South African life in general, whether we are talking of human settlement, the transport system or the economy. We generally make a distinction between the first and second economies, but a massive third economy is developing. There is thus massification at many different levels. The issue is whether to prepare teachers before introducing mathematical literacy as a subject, or whether to concentrate on democratisation and broadening our assets as the first point of departure. On a number of questions, South Africa has to take a position on the issue of equity *versus* standards, and equity *versus* quality. This has implications for implementation. I believe that teacher development should be addressed in a later discussion.

A delegate raised the issue of the ability of teachers to assess in the classroom. It was noted that there seem to be disparities in the way teachers assess learners in grade 12. Coupled with that is the fact that throughout the previous 11 years of schooling, the assessment is internal, and learners engage in much group work. Teachers undergo assessor training, but we still find that assessment is not done at the level at which it should be in the classroom in order to prepare learners for assessment in grade 12. Teachers tend to orient their teaching towards answering the question paper rather than for knowledge. The speaker responded:

> On the issue of assessment, at FET level 75% of the assessment depends on the final examination, and only 25% comes from the year mark. At GET level the final examination counts only 25% and the year mark 75%. The NCS for grades R–9 was developed first. The NCS for FET was based on the grade R–9 NCS, but when it came to assessment, it was felt that there should be reliance on external assessment (with the exception of life orientation) for several reasons: (1) at the time, it was not possible to rely on the capacity of teachers to assess; and (2) the public have reservations about the capacity of teachers to assess. Assessment is still a burning issue. Because assessment is part of the curriculum, teachers are expected to be teachers as well as assessors. I do not have answers but welcome suggestions.

Another delegate picked up on the comments made in the presentation about the possibility of establishing so-called third-tier institutions. This debate was started by the previous Minister of Education and is continuing. It was felt that perhaps we need to start discussing certain specialised schools to prepare people for particular careers, for example, in sport, art, music or engineering. As we prepare learners for citizenship in general, there are ways in which we could also prepare them for specialisation. A delegate suggested that one of the big questions we should consider is the point at which we allow differentiation. At present, this takes place only after grade 12. We do now have a National Certificate (Vocational), but should we allow learners to differentiate their areas of interest and ability sooner? A further comment was that the new Ministry of Higher Education and Training recognises that tertiary education is not sufficiently varied in that the technical sector has not been developing artisans, who are very necessary. Engineering does not require only degreed people but also technicians and artisans. Those who continue to tertiary education are not going only into academic study, but need to go into a whole range of areas of further education. This is something we should bear in mind. The speaker responded:

> I agree that a larger percentage of learners should continue to higher education, not only to the traditional universities but also to universities of technology. Higher education is increasingly trying to cater for different types of needs, targets and potential and should therefore be able to draw in a larger number of people. In order to do so, we will also need to increase the infrastructure of higher education institutions. In discussions about the human resource development strategy, we may need to differentiate between the roles and responsibilities of the various types of institutions.
>
> The presentation referred to the possibility of a third tier of schools comprising specialised schools. The debate acknowledged that the South African Schools Act allows provinces to establish specialised schools. However, it was proposed that the Minister should declare certain national (rather than provincial) specialised schools. Another issue raised was the possibility of revisiting the packaging of subjects in the curriculum in order to allow specialisation. The debate took place under the previous Minister of Education, and the stance of the current Minister of Basic Education

on the matter is not known. The intention is to focus on the foundation of education before the establishment of specialised schools can be entertained.

The consolidation of separate systems of education into a single one is almost complete, and subjects have been rationalised to a core set. In the next phase, it may be necessary to revisit the way in which subjects are organised so as to meet the needs of society in general as well as the economy and possibly to consider the need for new subjects.

A delegate commented on the disjuncture between the intended, implemented and examined curricula. These observations were made from the perspective of physical science:

> We are noticing a big 'sell out' between the vision that was proposed by the original national curriculum and what comes out at the end in terms of the examined curriculum. With respect to the learning outcomes, the previous matriculation examination would test mostly knowledge and understanding. The vision of the new curriculum was to test things such as the ability to design an experiment, science and society, and the nature of science. As the examination guidelines are published, they are gradually reneging on those learning outcomes. The department has 'smuggled' in problem-solving, defined as a calculation that requires more than one step. There seems to be a sort of *de facto* 'slippage' back to the old matriculation, rather than giving effect to the vision of the curriculum in the way it was originally designed.

In response, another delegate commented that these observations about the slippage evident between the vision and the reality are hardly surprising:

> The curriculum (particularly the science curriculum) seems too ambitious in thinking that within the time span available at school, it is possible to train learners to think at a higher level about the impact of science on society. The reality seems to reflect a lack of capacity in schools and among teachers. With respect to the unintended consequences of the broad national curriculum, it is true that the new curriculum severely undercuts the option to enter the technical professions. There is a widespread perception that the dropping of standard grade mathematics from the curriculum severely impacted on technical universities in that cohorts of students that would have gone that route now no longer have the necessary qualifications, and mathematical literacy is not meeting that requirement.

The speaker responded:

> The observation about the difference between the intended, implemented and assessed curricula is correct. This symposium's discussions on teacher education should interrogate the issue more thoroughly. This type of disjuncture does not exist only in South Africa. A vision is created in an office, but many aspects may not be taken into consideration. This is a challenge in any organisation, especially when dealing with large numbers of people. I have had the opportunity of visiting the districts and observing the challenge first hand. I cannot speak on behalf of the Departments of Education, but the need not only to work with schools but to support them profes-

sionally has been acknowledged. This cannot be done overnight. For example, teachers that are used to assessing only content now have to deal with scientific enquiry. If we succeed in teacher education, we will go a long way towards addressing the issue.

Chapter 4: STEM and Teacher Education

TEACHERS AND TEACHER QUALITY: A CRITICAL ISSUE IN SCHOOL MATHEMATICS AND SCIENCE

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Introduction

This paper will consider how we understand mathematics and science teachers within the South African schooling system and how their identities, knowledge and practices are related to issues of quality mathematics and science education. In order to do this, it will be necessary to understand what is meant by quality in our context, given present realities. The paper will explore the current production of new mathematics and science teachers and reflect on the need for higher education institutions to be responsive in the development of their curricula to ensure that sufficient numbers of new (quality) teachers are produced. In addition, the profile of existing mathematics and science teachers will be considered and issues around how we should support practising teachers in the schooling system through continuing professional development (CPD) will be considered.

Quality teachers

The McKinsey Report (Barber & Mourshed, 2007) investigated high-performing education systems in OECD countries. Two important findings of the study were:

- The quality of an education system cannot exceed the quality of its teachers.
- The only way to improve outcomes (learner performance and the quality of education that learners receive) is to improve instruction.

South Africa has many good-quality teachers in the system, including mathematics and science teachers, who work under varying circumstances, some very difficult and challenging, and do well. However, we also know that there are large numbers of teachers (and schools) who are not managing as well. The country has a differentiated system, a legacy of our apartheid past that we cannot ignore.

Consideration has to be given to how to achieve better-quality education across the whole system. This is seen as a national priority and is expressed in the National Policy

Framework on Teacher Education and Development (NPFTED) (DoE, 2007) in the slogan *"More teachers, Better teachers"*. This underlines the point that while we need to ensure we produce greater numbers of new teachers, particularly in priority areas such as mathematics and science, the quality of such teachers is just as important as the number produced.

Teacher quality has at least two facets: qualifications, that is, having access to high quality formal (institutionalised) academic and professional learning for the purpose of teaching, both for initial teacher preparation and for career path development; and quality teaching in the world of work (classroom/school). The latter is dependent on personal commitment and continued professional learning, as well as teachers' access to powerful forms of knowledge, including a broad and deep understanding of their area of specialisation (subject/learning area/phase) both in-and-for itself and in-and-for teaching.

In our context, both aspects need to be considered. Our aim is to produce teachers who:

- have a deep understanding of the knowledge and practices underpinning their specialisation;
- know how to transform this into quality learning opportunities for children in their care;
- are committed to the profession, children in their care, the school community and uplifting society more generally;
- continuously learn in-and-from practice.

This goes beyond content knowledge to commitment and disposition – the best teachers are passionate about their subjects and they inspire learners and spark interest and commitment within them too. An issue such as this is not easily addressed, and cannot be solved within the current system by simply offering teachers more content or more training. These aspects relate fundamentally to the question of teacher identity: a teacher's consciousness and conscience, and ways of knowing and being.

In order to improve mathematics and science teacher quality, we must consider the supply of future mathematics and science teachers – how we attract them into the profession, prepare them, induct them into the world of work, and retain them once there. We do not do this very well at present. While we are getting better at attracting young, capable matriculants into teaching, as will be shown below, the initial education they receive is highly differentiated across the system. Once they graduate, newly qualified teachers are generally thrown into schools and expected to be immediately ready to teach. Only the fortunate few find themselves in a school with a head of department or group of supportive colleagues that induct them into the world of work. Others have to make do with the situation in which they find themselves, and the prevailing ethos of the school soon dominates.

We must also consider the existing cohort of mathematics and science teachers. How do we support them to take responsibility for their own professional development and become confident and competent to teach the national curriculum? How do we change their attitudes towards newly qualified teachers, and help them to provide supportive environments for new teachers when they begin their teaching careers?

The development of new mathematics and science teachers

Currently the initial preparation of mathematics and science teachers is through two specific routes: a four-year Bachelor of Education (BEd) degree, which integrates the academic and professional aspects of learning to teach; or, a general bachelors degree such as a Bachelor of Science (BSc), with subjects relevant for teaching, together with a Postgraduate Certificate in Education (PGCE), a professional teaching qualification. The Department of Education recognised that there was a critical need to ensure the supply of new teachers, especially for mathematics and the sciences, and therefore introduced the Funza Lushaka Bursary Scheme in 2007, a national service-linked bursary scheme. This, together with a sister programme, the Teacher Recruitment Campaign, has revitalised the initial teacher education sector and has had the effect of a 50–100% increase in applications to initial teacher education programmes across the different universities, and an average increase of about 35% in first-time enrolments in 2009. In 2009 the scheme supported a total of 9 294 students across all specialisations, which is approximately 25% of the initial teachers in the system. The scheme has been used to lever up the system, particularly the quality of new entrants, by setting academic criteria and ensuring that the universities apply these consistently.

It is instructive to consider the trends in the bursary awards to better understand the current production of new mathematics and science teachers. The first thing to note generally is that universities are focusing on the BEd rather than the general degree plus PGCE route for initial teacher education. Table 4 indicates that 91% of all bursaries were awarded for the integrated degree programme in 2009.

Table 4: Distribution of 2009 Funza Lushaka bursars across initial teacher education programmes (n = 9294)

BEd 1st year	BEd 2nd year	BEd 3rd year	BEd 4th year	PGCE	Other bachelors degrees
30%	24.6%	21.2%	15.3%	6.6%	2.3%
91%				7.0%	2.0%

Source: DoE (2009a)

It is also noted that a very small percentage of students (2%) are being supported to complete other bachelors degrees. This has to be considered particularly with respect to the development of grade 10 to 12 teachers, that is, teachers for the Further Education and Training (FET) phase. Why are faculties not encouraging capable students to take general degrees in mathematics and science if they wish to become teachers? What are the contents of the BEd programmes for these specialisations? The current policy (DoE, 2000) for programmes leading to qualifications for grade 10 to 12 teachers is that subject content within the disciplines underpinning the teaching specialisation must be completed to at least second-year university level. Do all BEd programmes meet these criteria?

When we consider what programmes bursars are supported on across the different phases, it becomes clear that universities favour the BEd route, and are also biased towards FET programmes. The combination of the FET bias and the BEd route implies that education faculties are focusing their energies on programmes that are held within their faculties. Table 5 shows the 2009 distribution of bursaries across different phases, which confirms that 56.3% of all bursaries are awarded to student teachers who will qualify to teach in the FET phase.

Table 5: Phase specialisation distribution of 2009 Funza Lushaka bursaries

FP	FP/IP	IP	IP/SP	SP	SP/FET	FET
17%	0.1%	9%	10.1%	7.4%	18.4%	37.9%
43.6%					56.3%	

FP = Foundation phase (grades R–3); IP = Intermediate phase (grades 4–7); SP = Senior phase (grades 8–9)

Source: DoE (2009a)

A further disaggregation of the data (Table 6) shows the learning area/subject specialisation of student teachers supported across the various phases.

Table 6: Learning area/subject specialisations of student teachers supported through the Funza Lushaka bursaries (2009)

Learning area specialisations (IP/SP)		Subject specialisation (FET)	
Specialisation	**N**	**Specialisation**	**N**
IP Mathematics	520	Mathematics	1147
IP Natural Science	473	English Language	814
IP English Language	424	Physical Sciences	609
IP African Language	327	Life Sciences	601
IP Technology	279	African Language	569
		Computer Application Technology	416
SP Mathematics	508	Mathematical Literacy	142
SP English Language	403	Agricultural Sciences	120
SP Nat Science	383	Information Technology	99
SP Technology	311	Eng Graphics & Design	86
SP African Language	289	Civil Technology	34
		Electrical Technology	32
		Mechanical Technology	16
		Agricultural Technology	15

Source: DoE (2009a)

Table 6 illustrates that the highest numbers of student teachers in each phase are specialising in mathematics, which is encouraging. However, there are far fewer focusing on mathematical literacy, which is of concern since this is a new school subject and there is a critical shortage of teachers able to teach this in the system. It is also clear that half as many physical science teachers and life sciences teachers are being supported.

While it is encouraging to see a growing interest in teaching, and increasing numbers of successful school learners being attracted into the profession, the figures do not show the extent to which we are meeting the need for new teachers in the system. This requires an analysis of teachers teaching in the system and an understanding of the supply, demand and utilisation of teachers currently in the system. Before discussing the qualification profile of practising mathematics and science teachers, a few comments will be made with respect to the issue of the quality of initial programmes.

If the majority of new FET teachers are being educated through BEd programmes, we need to consider whether this is a problem or not. Should universities be encouraging students who are setting out to become mathematics and science teachers to complete general degree programmes first to get steeped in the disciplines before studying teaching? Or does the integrated programme provide access to this type of disciplinary learning? We need to consider how such BEd programmes are structured and how they deal with issues of knowledge and identity discussed earlier. There is insufficient space to deal with this in detail here; however, consideration must be given to the balance between different types of knowledge and practices integrated into the BEd programme. Specifically, there are at least three types of specialist learning required: the academic discipline underpinning the specific school subjects to be taught (for example, the study of mathematics in-and-for itself); specialised educational research focused in the area of teaching (for example, the study of mathematics education and mathematics in-and-for teaching); and learning in-and-from teaching practices (for example, the study of mathematics teaching practices and practising mathematics teaching).

Recent research has shown that there are differentiated curricula across higher education institutions and different understandings of what selections of knowledge and practice should be included in initial teacher education programmes and how these should be made available to teachers (see Parker, 2009). For example, all institutions that offer teacher education regard content knowledge as important and allocate the majority of specialist credits in their initial programmes to content. For some institutions, this is interpreted as ensuring that teachers know the school curriculum, whereas for others content may be understood as advanced knowledge and specialisation in the academic discipline underpinning the subject to be taught at school. While the focus on content knowledge is clearly privileged across the system, the same cannot be said about learning from-and-in-practice. The majority of institutions do not provide specialist and assessed learning opportunities to enable the development and use of knowledge-in-practice (Adler, Slonimsky & Reed, 2002). It is clear from this differentiation across the system that there is a lack of effective regulation to ensure responsive curricula in initial teacher education programmes.

Questions that can be posed about the ‘what’ and ‘how’ of initial mathematics and science teacher education programmes include the following:

- Selections into the curriculum: What should be privileged and why?
- Who should teach teachers: Mathematicians/scientists? Mathematics/science education specialists? Expert teachers? Perhaps all of these for different aspects?
- How should teachers be taught?
- Where and when?

The responsibility for these decisions rests with HEIs, resulting in differentiated responses across institutions. The present policy is very general and generative and is not suitable for regulating what is provided. It is likely that the new policy for qualifications in teaching will build in stronger regulatory tools to enable the department to ensure that institutions provide the kind of teachers required by the system. We need our higher education institutions to ensure that the programmes they offer to mathematics and science teachers produce the kind of teachers we need to uplift the system in the long run.

Continuing professional development of mathematics and science teachers

Currently there is a focus on upgrading the qualifications of existing teachers through formal qualification programmes. There are two such qualifications used, the National Professional Diploma in Education (NPDE), which targets under-qualified primary teachers with old apartheid-era (one- or two-year) teaching certificates, and the Advanced Certificate in Education (ACE), which targets teachers with old three-year college diplomas. With respect to the ACE programmes, there are very few that are taken in subjects taught in schools. Table 7 illustrates this by comparing the total registrations across all ACE programmes with registrations in programmes aimed at mathematics and science teachers.

Table 7: Registration in ACE programmes (2008)

	Maths literacy	Maths/ MST	Science education/ physical science	Life sciences	All maths/ science ACEs	All ACEs
ACE registrations	876	3 542	389	201	5 005	43 803
No. of programmes	9	30	10	5	54	

FP = Foundation phase (grades R–3); IP = Intermediate phase (grades 4–7); SP = Senior phase (grades 8–9)

Source: DoE (2009a)

It is sobering to note that in 2008, 43 803 teachers were registered across all ACE programmes at the 23 HEIs offering teacher education and development programmes. At the same time, we estimate that approximately 35 000 teachers were registered for initial teacher education programmes. Of these ACE registrations, only 5 005 were for mathematics/science technology teachers, with the majority of these (3 542) focused on mathematics or a senior phase mathematics/science and technology combination. The vast majority of ACE registrations were in management and inclusive education. Before reflecting on the use of these ACE programmes for upgrading, we first need to understand who our teachers are.

Who are our mathematics and science teachers? What is their qualification profile? It is through getting a picture of practising teachers that we can consider how best to support different needs in the system. If we are to use the resources of universities to provide qualification programmes, what kind of programmes should be supported? There is also the question of short CPD programmes and how these should be used.

The first thing to note is that the data we have on the specialisations of our teachers are not good enough. Currently, once a teacher is qualified to teach, they are taken into the system and can be utilised where needed in a school and not necessarily in the specialisation for which they were educated. A qualified teacher is qualified – what they are qualified to teach is not always taken into account in their utilisation. The department is currently working on developing a national database and Human Resources Management Information System (HRMIS) that will store details of all teachers' qualification specialisations. However this is not yet available.

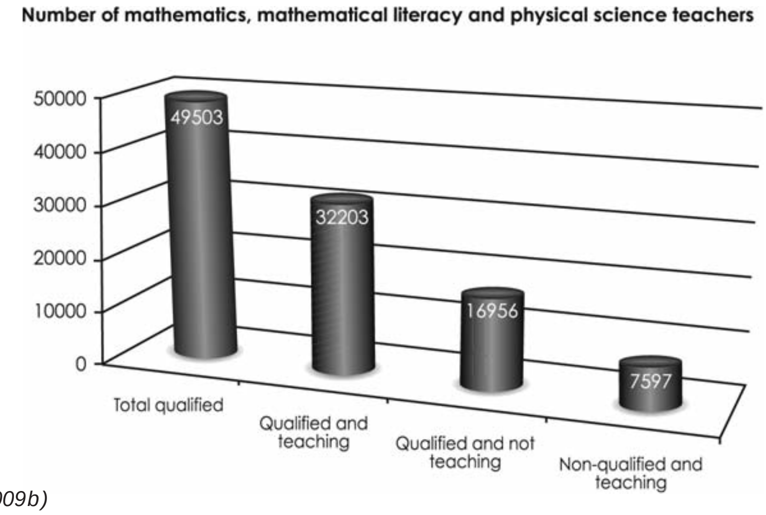
Two sources are utilised for building an understanding of the profile of currently practising mathematics and science teachers:

- A survey carried out by the Department of Education in 2008 (DoE, 2009b) that focused on the supply of and demand for mathematics, mathematical literacy and physical science teachers. A very high proportion of secondary schools, 6 991 schools in total, were surveyed, with 5 420 returns (which represented a 78% return rate). The information gained gives a broad picture of these teachers practising in the system.

- A teacher qualification survey carried out by the department with the HSRC in 2008 (DoE & HSRC, 2009). The census-style survey worked with a statistically significant sample of 600 schools, including all types and phases, across all provinces. The survey included all teachers in these schools. There were 226 FET mathematics teachers included in the sample. The information gained from the survey is limited, but is informative and can assist us in understanding the profile of teachers.

Figure 2 provides a graphical representation of the total number of qualified mathematics, mathematical literacy and physical science teachers, as well as the utilisation of qualified and non-qualified teachers to teach these subjects. Qualified means being qualified with at least a three-year college diploma with the equivalent of one year of university-level study in the subject being taught. These teachers could have a variety of qualifications, some university degrees and other college diplomas.

Figure 2: Qualifications and utilisation of mathematics, mathematical literacy and physical science teachers in ordinary public schools in 2008

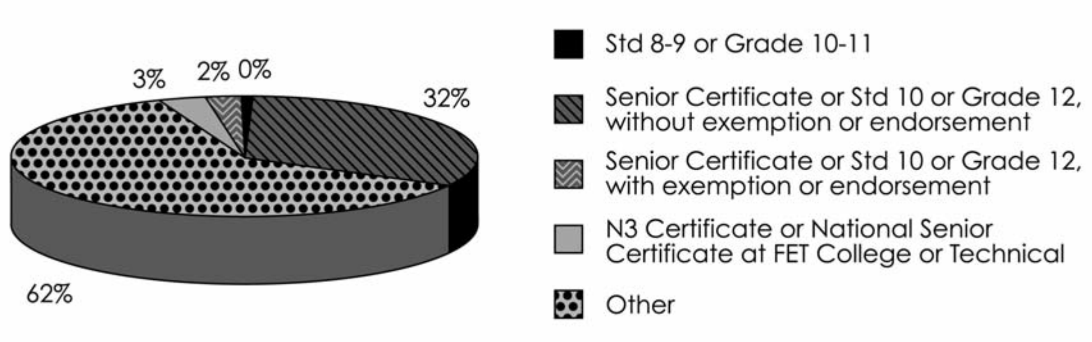


Source: DoE (2009b)

Of the 49 503 qualified mathematics, mathematical literacy and physical science teachers working in public school, 32 203 (65%) are teaching these subjects and a further 16 956 (35%) are not teaching these subjects. At the same time, there are 7 597 teachers that are teaching the subjects but are not qualified to teach them. This seems problematic, although some of the qualified teachers that are not teaching may be in school management positions, or may be teaching a second subject for which they are also qualified. Clearly this kind of data is useful in that it highlights that there are qualified teachers in the system who may not be teaching what they are qualified to teach and that there are also a fair number of unqualified teachers teaching in our schools. It points us to the problem of utilisation of qualified teachers in the system. However, the data do not give us any specific detail of the background qualifications of teachers.

Figures 3 and 4 draw on the teacher qualification survey (DoE & HSRC, 2009) to tease out a more nuanced picture. However, the information available here focuses only on mathematics teachers. While information was collected on all teachers in the system, the data were not analysed with respect to science teaching. Figure 2 shows the highest secondary school qualification of practising FET mathematics teachers. This highlights that of those teaching mathematics, only 62% achieved a senior certificate with a university-level entrance pass. This does not tell us anything about the actual level of matriculation mathematics of these teachers, nor what their school mathematics achievements were. It does indicate that a large proportion (38%) would not have gained entry into a university, a reflection of our apartheid past.

Figure 3: Proportion of FET phase mathematics teachers by highest secondary school qualification (n = 226)

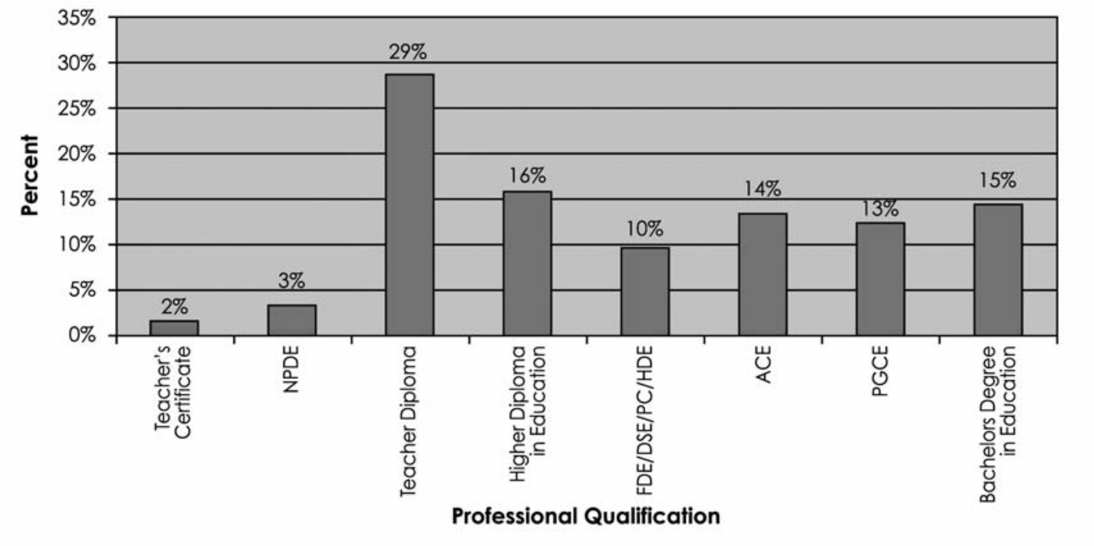


Source: DoE & HSRC (2009)

Figure 3 illustrates a further breakdown of these teachers' qualifications. Here their professional qualifications are considered. The range of teaching qualifications is a reflection of the differentiated teacher education landscape during the apartheid years. It is noted that of the 226 FET teachers teaching mathematics, 184 (81.4%) are professionally qualified. Approximately 20% are professionally unqualified.[6]

[6] Note that professionally unqualified graduates would be included in this figure, that is, teachers who have degrees but do not possess a PGCE or equivalent.

Figure 4: FET mathematics teachers' highest professional teaching qualification (n = 184)



Source: DoE and HSRC (2009)

This provides us with a very useful illustrative proxy of the qualification profile of practising FET mathematics teachers. First we note that of the professionally qualified mathematics teachers, 28% have either a PGCE[7] or a bachelors degree in education.[8] Seventy-two percent of the teachers qualified though the old colleges of education and have a variety of different qualification types, with the majority of these having a three-year teachers' diploma. This illustrates that while we are moving towards teaching as a graduate profession (all new teachers are required to qualify through degree programmes), we are a long way away from all teachers being graduates. What Figure 4 does not show us is what the specialist subject training of these teachers is.

Further illuminative information gathered by the survey is the breakdown of teachers with academic qualifications.[9] Of the 226 FET teachers in the survey who teach mathematics, 36% (82) have specialist academic qualifications of some kind. Of these teachers, 57% (47) have courses in mathematics subjects, 63% (52) have courses in mathematical literacy subjects; 21% (17) have courses in physics and/or chemistry subjects; 13% (11) have courses in life sciences subjects, and there are small numbers across a wide range of other subjects (51).

While the data are limited, they do provide some insights into the qualification profile of practising mathematics and science teachers and can be used to guide us in our thinking around the kind of support we need to provide for teachers practising in the system. Specifically in relation to mathematics teachers, we note that while 81% of

[7] Or equivalent, for example an old university Higher Diploma in Education (Postgraduate).

[8] This includes the current BEd-type qualifications, as well as the older degree programmes such as the Bachelor of Pedagogics , BA(Ed), BSc(Ed), etc.

[9] Note that this includes all the professionally qualified teachers who have PGCE-type qualifications, teachers who may have had college qualifications and then later completed degree studies, as well as teachers who are professionally unqualified with degrees, national diplomas or technical certificates.

these practising teachers are professionally qualified, their academic backgrounds are very limited, with only 47 of the 226 teachers of FET mathematics (21%) having some university-level courses. These teachers are illustrative of our mathematics teachers, and are the teachers who prepare learners throughout the system for mathematics (not mathematical literacy).

This takes us back to considering what kind of CPD is required by practising teachers of mathematics and science, particularly given the earlier discussion on quality and teacher identity, and given our limited yet more nuanced understanding of their qualification profile. It should be understood that providing these teachers with more qualifications will not necessarily realise our goal of quality teachers. The focus on upgrading programmes (particularly the ACE) that is currently weighing down the higher education system will not necessarily bring with it better results, even if it is more focused on subject content than on more generic knowledge. At the same time, short workshops that do not evaluate teacher learning are also not helpful. It is important that we move away from a qualification 'upgrading' mentality to a system that supports teachers to become more confident and competent in what they teach. We need to encourage teachers to take responsibility for their own professional development and reward them for doing so.

We need to use qualifications to enable career path development, in other words, to identify and develop excellent mathematics and science teachers so that they can become leaders within the system – teaching and learning specialists who are empowered to lead professional development/teacher learning communities and mentor and coach other teachers within their localised contexts to develop their knowledge and practices for teaching and their identities as mathematics/science teachers. We need to develop short, pedagogically sound and content-rich programmes for teachers focused on identified areas of need related to what they actually teach. These need to be quality-assured and be offered by a variety of providers to meet the vast need. Subject associations could play an important role in this regard.

Responsibility, responsiveness and accountability

Unless together we ensure a supply of new teachers into the system with the qualities that have been identified, we will not succeed in changing the system in the long term. However, even if we do this, teachers that are deployed in schools that are dysfunctional can soon unlearn what they have been taught in their preparation and take on the characteristics of the rest of the teachers in the school, or leave the system altogether. Unless there is a critical mass of professional teachers in a school and there is good leadership, it is very difficult for new teachers to acclimatise and develop into professionals committed to their learners and their careers. Thus we have to assist teachers in the system to take responsibility for their practice and continuing professional learning. It is noted that this is not essentially about the resources that a school has; it is about ethos and commitment, although the physical and material conditions of a school do have a major effect.

We must make sure that programmes aimed at developing and supporting teachers are more effectively regulated. Higher education institutions need to be more accountable for what they produce, and more responsive to the context and the students entering the system to ensure that the trained teachers that emerge are able to work with the new curriculum and new forms of knowledge required, as well as with learners in a variety of impoverished contexts. It is vital that new teachers have access to powerful forms of specialist knowledge (access to their disciplines and knowledge and practices for teaching) and that teacher education programmes are designed to take this into account. HEIs need to ensure that they focus their energies on producing sufficient numbers of well-qualified new teachers, and do not sacrifice this in order to take in large numbers of funded students in upgrading programmes, or focus on the higher end (honours and masters degrees) where there are higher subsidies.

The National Department (and in future the new Department of Higher Education and Training) has a responsibility to monitor the design of curricula and to regulate HEIs so that they provide programmes that meet the needs of the basic education system. It also has a responsibility to set policy, to guide provinces in the implementation of the policy and to use funds to lever and strengthen the system. Provincial education departments need to be more responsible as well. They need to ensure that they do not make unrealistic demands on HEIs with respect to upgrading qualification programmes. They must also ensure that new and existing teachers are productively employed and utilised in their areas of competence. The relationship between the national and provincial departments is a critical issue to be dealt with, particularly with respect to teacher education. A newly qualified teacher induction programme must be put in place to ensure that young teachers are supported as they enter the system.

Conclusion

Teachers are a critical aspect of ensuring quality mathematics and science teaching. We need to produce more teachers and ensure that they are well qualified to teach, and that they have developed specialist identities that meet the needs of our system. HEIs have an important role to play in this production and should be held accountable for the products that they produce. The National Department of Education needs to grow the bursary scheme so that it produces sufficient numbers of new teachers to start having an impact on the system. However, unless provincial departments ensure that these teachers are productively employed in their area of specialisation, and good induction programmes for newly qualified teachers are put in place to ensure that we support them and retain them once in the system, we will continue to be bedevilled by problems. Currently practising teachers also require support; they require assistance with content and pedagogical content to enable them to teach the NCS well. Training on its own will not suffice, however, teachers have to become committed to their subjects and practices, and this is a question of identity.

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DISCUSSION

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In the discussion following Dr Parker's presentation, a range of comments were offered and questions raised, and these are presented in broad topic areas below. Dr Parker responded to some with further information, and this is captured.

Recruitment, retention, bursaries and incentives

A range of questions and comments were related to the shortages, particularly in physical science, and the bursaries and other incentives that are or could be provided:

1. The production of physical science teachers remains very poor, despite the Funza Lushaka bursaries. These seem to attract teachers to mathematics but not physical science. Are these bursaries being publicised sufficiently to BSc students?

2. It would seem from the presentation that the Department of Education would prefer teacher education to follow the route of a general degree plus PGCE; however, the recipients of the Funza Lushaka bursaries are skewed towards BEd. Would it not make sense to specify to HEIs the proportion of students to be admitted for a BEd in order to ensure the desired spread? If it is left to provincial departments of education to decide, this will not happen. Such a strategy could make a significant difference.

3. In our Department of Applied Mathematics, students are accessing the Funza Lushaka bursaries. However, the issue remains as to whether these students aim to become teachers and remain in the profession. The promotion of teaching as a profession in science faculties needs to happen in tandem with encouraging the take-up of the bursary scheme.

4. Could there be incentives for ongoing training, for example, credits matched with various offerings enabling teachers to exercise more choice in what they attend?

5. Should systematic in-service training not be mandatory for teachers? This question was based on the speaker's experience of attending a training session on evolution, a new topic in the curriculum. Yet there were only five teachers attending.

6. ASSAf should spend time and effort on enhancing the attractiveness of the teaching profession. At meetings about six years ago, a decision was taken that one way of improving mathematics and science teaching was to provide teachers of those subjects with more money, and a Minister publicly announced that this would happen. However, there has been no money from National Treasury for that purpose. ASSAf should apply pressure in that regard.

7. What about projections? If we remain on the same trajectory as at present in terms of teacher training at the various levels, will we be facing a crisis in the provision of mathematics and science teachers in five years' time or not? I venture to suggest that we do have a crisis and will have one later on. The figures that have been presented suggest that the situation is far worse with respect to science teachers than mathematics teachers, and this issue would appear to be under-discussed in this Forum. Have projections been done? If we reach agreement that we are facing a crisis, South Africa may have to take strategic decisions, for example, to quadruple resources and to make teacher training a national priority. If we are able to erect stadiums at huge expense merely for a World Cup, why can we not inject millions into the training of mathematics and science teachers? I believe that we need to call for this.

8. There are large numbers of Zimbabwean teachers in our system. Many of them are good mathematics and science teachers. What has been the impact of these teachers on the system?

Dr Parker responded that on the issue of the projections, numbers in initial teacher education had increased over the last three years. Although the crisis does lie in the numbers, it also lies elsewhere. South Africa currently produces between 8 000 and 9 000 teachers per annum, and a recent audit showed that about 12 000 teachers leave the system each year. This is a relatively small percentage, representing only about 3.5% of all teachers. These numbers are difficult to come by, and some accounts are that there are as many as 20 000 teachers leaving the system each year.

However, if the department is able to get a large enough budget for teacher education – since we believe that the state will have to select candidate teachers and pay for their training – we believe that we will be able to produce 15 000 teachers a year within a relatively short period of time. In the interim, we have many well-qualified Zimbabwean teachers to fill the gap. The crisis therefore does not appear to be in the production of teachers, although the numbers hide the identity of those that are being trained, as we do not seem to be training the disciplinary specialists that we need.

However, there is a crisis in getting teachers into the schools and teaching. The Funza Lushaka bursars have to commit themselves to teaching anywhere in the country, and sign a contract to that effect. The graduates are the mathematics and science teachers that we so badly need, yet of the approximately 1 000 graduates in 2008, only 61% have been deployed in posts to date. Probably all of them will have posts by the end of the year, but we should be able get them into posts on the first day of the school year. This is a systemic problem. There is a story of one of these new teachers being chased away from a school because there was a local person occupying the post. Once a person is a teacher, they can be deployed in any post. One therefore finds that vacancies may be filled by a temporary teacher or a member of the community, who is not necessarily qualified in the right subject. The vacant posts may not be linked to a specific subject. The governing body of the school takes decisions on the employment of teachers in a school, and the national department has no control over this.

Providers of teacher education and the re-opening of the colleges of education

There were numerous comments on the appropriateness of the qualifications currently on offer, as well as the suitability of the university as the provider of all teachers in the system. Linked to this was the question of the closure of the colleges of education in the 1990s:

1. Are universities the best place for teacher education? What would the implications be of reopening the colleges of education? Universities are very liberal institutions, creating a liberal environment, but teacher education needs direction and regulation. Education is not value-free. Perhaps teachers that teach grade 12 could come from the university system, in order to provide the transition for learners to higher education. However, those that teach in the middle school could possibly be educated through teacher education colleges, since one does not need a degree to teach mathematics at that level. If teacher education colleges were to be reintroduced, it would encourage the professionalisation of the teaching profession. The teaching environment does not create much competition because of the degrees of sameness.

2. Is it just a rumour or a fact that the reintroduction of colleges of education is being considered? If so, HEIs need to know from their clients, the departments of education, why they are not satisfied with the way in which universities are educating teachers. Universities should be proactive in this regard if that is the case.

Dr Parker responded that there is currently public debate about the colleges of education as a result of a commitment made by the ANC convention at Polokwane. The matter has thus become a political issue, and there is a perception that the crisis in education stems from the closure of the colleges and that universities are not producing the kind of teachers we need. However, the reality is that most of the teachers in the system were trained in colleges of education, so the universities cannot be blamed for the current situation in schools. During the process of merging the colleges with HEIs between 1996 and 2000, the provinces recognised that teacher education was to become a national competence and began to rationalise colleges. By the time the colleges were incorporated into HEIs, there were no colleges that were viable on their own in that they did not have enough students and thus had to become part of existing institutions.

Another difficult issue is that the funding that went into the approximately 150 colleges of education remained in the provinces to be used for other purposes and did not come into HEIs in order to assist them in expanding to meet the need and take on the function. Only in the last three years is the problem being addressed through the bursaries and the recapitalisation of the system. Institutions were invited to make applications. We need to ensure that we have a system of institutions that can produce what we require.

Qualifications for pre-service teachers and for upgrading/retraining teachers in service

Comments here were related to the adequacy of the various qualifications, as well as to who was being accepted/recruited into these:

1. Neither the BEd (Hons) nor the ACEs as they are running are appropriate for what is needed – reorienting teachers in the system to their new roles. The honours courses are too research and academically oriented. The ACE as initially conceived as a level 6 qualification spent more time on higher-level mathematics and insufficient time on supporting teachers in the content of the new curriculum, and ways of teaching it. In addition, practices for enabling success, like resubmission of assignments over and again, does the system harm.

2. The selection of students into various ACEs in order to make up the numbers is problematic. The provincial departments of education sometimes select early childhood development teachers to enrol for an FET ACE. Teachers tend to elect to enrol for an ACE because they want to get out of the teaching profession or get out of teaching and into school management. That is why so many of them want to do the ACE in management. Many think it will equip them to go into industry.

Quality of the teacher

A related discussion was on quality with respect to the teacher, and whether quality is a function of passion and commitment or professionalism:

1. Resources and remuneration are key in a profession – we should take anyone in and raise them to the level of professionalism required. I am concerned that if we continue to look for people with an incredible blend of passion and all the other things we would like to see, we will not be able to find them.

2. For the last two years, I have been teaching second-year BEd students a course on the nature of science. There were 40 students in the class in each of the two years, and they are due to become physical science teachers. It appears that the bursaries attract a diverse group of people that see it as the route to a degree rather than those that want to teach mathematics or science. It was clear that these students of the nature of science had no actual love of science. So, in contrast with the suggestion that instead of looking for passion, we take anyone that is competent and train them as teachers, I believe that we do need people with passion. ASSAf should gather evidence about who becomes a teacher, who remains a teacher and who leaves teaching.

Some of the discussion on quality education of teachers, both prospective and in-service, focused on the importance of communities of teachers working together in schools to fulfil their roles.

Chapter 5: STEM at the interface between school and higher education

MIND THE GAP: SOME REFLECTIONS ON STEM AT THE INTERFACE BETWEEN SCHOOL AND HIGHER EDUCATION

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Introduction

With the first intake of the new National Senior Certificate (NSC) students entering higher education in 2009, there has been considerable 'hype' – bordering on hysteria – in the media and within our higher education institutions (HEIs) around students' levels of preparedness for higher education (as indicated in the National Benchmark Tests [NBT] results), concerns about high failure among first-year mathematics and science students, and a general distrust of the new NSC.

However, concern about falling standards in the school-leaving examination and the 'gap'[10] between students' capabilities and universities' expectations is not new in South Africa. Akoojee and Nkomo (2007: 387) highlight several previous studies that foregrounded students' levels of underpreparedness for higher education. For example, a study commissioned by the Joint Matriculation Board in 1963 found that only 55% of the first-year students graduated. The reasons given for failure were poor school preparation and the 'weaknesses' of university teaching and learning. An even earlier study, commissioned by the Minister of Education in 1936, found high first-year failure rates and attributed this to "a mix of the transition from school to university and the inadequacy of the university teaching system".

While concern about the articulation between school and higher education is not new, the introduction of the new school curricula in mathematics and physical science has precipitated renewed concerns about students' levels of preparedness, and concerns about the poor performance of the 2009 cohort in their first-year June tests. However, there has been very little systematic research into the situation, with most engagement at an anecdotal level in university staffrooms and corridors.

[10] The *White Paper on Higher Education* (DoE, 1997) refers to the 'articulation gap' between school and higher education.

What is the nature of the 'gap'?

While the anecdotal accounts that have tended to find their way to the media have highlighted the weaknesses of this 2009 cohort, in fact there is an equally compelling set of anecdotal accounts that amplify the strengths of these students. I will briefly give a flavour of each of these in turn.

In terms of weaknesses, students' poor mathematics skills are highlighted. Lecturers attribute this both to content 'gaps' – such as the geometry topics currently in paper 3, which very few students opt to write – as well as to difficulties with higher-level problem-solving. Some laments can be heard that the students can no longer memorise, and are less able to sit passively in class.

On the positive side, there are reports of students doing better than before in some courses, particularly in those courses that draw on students' strengths developed with the new school curriculum, including awareness of the wider contexts of science, and thinking about science processes in a more conceptual way. Some lecturers noted that the students are more confident and engaged in their laboratory work, again, perhaps, due to the greater focus on investigations and practical work in the new school curriculum. Students are also noted to be far more actively engaged, working productively in groups. Although students may struggle more with mathematics manipulations, some lecturers claim they seem less daunted by complex problems and persevere in tackling them.

Other than the plethora of anecdotal comments already summarised, there has been little systematic or scholarly investigation undertaken on the progress of the 2009 student intake. Two studies undertaken in 2009 provide illuminatingly contrasting perspectives on the performance of this cohort. The first study, entitled 'The first OBE cohort in Physics 1: Set up for failure?', examined the performance of the Physics 1 (major) class at the University of Johannesburg in 2009 (Winkler, 2009). This class saw a huge increase in enrolment in 2009 (from 375 to 512) since many more students met the entry criteria. The study found that the 2009 OBE intake were scoring 8–12% lower than the 2008 intake did. The implications drawn from the study were that:

- Tighter selection criteria were needed for SET programmes.
- A 13th school year should be introduced for talented learners, who would be assembled at a few well-resourced schools.

The second study was an analysis of the mid-year results of Physics 1 and Mathematics 1 for engineering students at the University of Cape Town over a five-year period (Wolmarans *et al*., 2010). The study found that there had not been a sudden decline in marks in 2009, but that the 2009 results were "part of a gradual deterioration in the preparedness of incoming students" over the period of the study. Since there had not been a sharp discontinuity in the students' results in 2009, the authors argue that the 2009 NSC could not be solely blamed for the decline. The study also found a low correlation between NSC results and first-year performance in mathematics and physics. The implications drawn from this study were that:

- Tighter selection criteria would not be useful (since the NSC was not well-correlated with first-year success)
- Educational strategies are needed in higher education that will assist underprepared students to succeed.

If we take these two studies together, there are some fascinating points of comparison. While the one suggests that the new NSC is the main problem, the other study demonstrates that there has been a gradual decline in performance over the past five years, and cautions attributing blame for the decline in grades solely to the NSC. While the one advocates tighter selection criteria, the second study suggests that this would not be a useful solution. While the one calls for a 13th year of school to prepare students for higher education, the other points to the need to find strategies within higher education to address the underpreparedness of students.

The first study's subtitle, 'The first OBE cohort in Physics 1: Set up for failure?', implies that the students have been set up for failure by the OBE system. However, an alternative question may be posed: 'Have these students been set up for failure by an unresponsive higher education system?'

Both studies are at pains to establish that the courses they examined remained unchanged during the period under review (in good scientific design, they have 'controlled' for that variable). However, the question I raise in this paper is this:

Why did the courses remain unchanged, when the students' experiences of learning mathematics and physical science in high school were different from previous cohorts?

It is important to note that the interface, or 'gap', between school and higher education is a worldwide concern, especially as school mathematics and science increasingly focuses more broadly on citizenship education, rather than just preparing students for university studies. For example, a report from Australia on the introduction of a new physics school curriculum, with a greater emphasis on relevant contexts of science, noted that while this had left students less well-prepared for university science studies, it seemed to have led more students to be attracted to taking science at high-school level (AUTC, 2005).

How should higher education respond to the 'gap'?

Broadly, there seem to be two possible responses within higher education to the 'gap' problem, and both have been represented in the anecdotal responses described above, as well as the implications of the two studies of the 2009 cohort:

Option 1: It's not higher education's problem

Here, the 'mind' in the 'mind the gap' logo takes on the meaning of 'avoid', 'sidestep it', as is the intended meaning in the London Underground context.

Option 2: Higher education needs to respond

Here, the 'mind' in 'mind the gap' takes on the meaning of 'to attend to, to tend, have care of oversight of', (as in the term 'child-minder' – not someone who minds or avoids children!)

Option 1: It's not higher education's problem

This perspective often dominates discussions in higher education, encompassing points of view such as 'it's the schools' problem, not ours', and 'the solution is to raise entry points, and hence to admit better students'. First year is often conceptualised as a 'filter' to 'weed out' those students who 'are not university material'. This is the realm of 'survival of the fittest'. The metaphors used are revealing: education as a technical process – with mention of 'filters' and properties of the 'raw material'; the more promising gardening metaphor is also evident, but the focus here is on 'weeding', rather than nurturing growth.

However, statistics on student participation rates in higher education show that this view, that 'it's not higher education's problem', is highly problematic: the very students to be 'weeded' or 'filtered' out are in fact the only pool of students we have to draw from. As much as it might seem an unpalatable truth to some academics, these student are the 'cream of the crop'. A recent study commissioned by the Council on Higher Education (Scott *et al.*, 2007) highlighted the extent to which student participation rates[11] in higher education are still very skewed along racial lines, namely, White 61%. Indian 50%, Coloured 12% and African 12%. This study also highlighted a high attrition rate in first year (30%), as well as an estimated maximum completion rate of 44% for the cohort. This means that while only 12% of the black age cohort enter higher education, less than 5% of this cohort succeed in any form of higher education. Furthermore, only a fraction of this 5% of students will be in STEM programmes. Therefore, in terms of social justice, equity and meeting national development needs (i.e. more scientists and engineers) Option 1 is quite simply not defensible. The statistics highlight that there is no other pool of students we can draw on by raising entry requirements or 'filtering out' those that are not 'university material' – these are the 'cream of the crop'. The findings of this study also challenge the existing degree structures of higher education by revealing that very few students in fact graduate in regulation time (Table 8).

Table 8: Percentage of students graduating in minimum time

Programme	Black (%)	All students (%)
Engineering	14	32
Life and physical sciences	11	21
Mathematical sciences	13	24

11 This study looked at the cohort of entering students in 2000. Participation rates are as a percentage of the 20- to 24-year-old age group. Note that in developed countries, the participation rates may be 70% or more.

These findings highlight that the three-year BSc/four-year BEng is in fact *not* the norm in higher education.[12] As educators, it is important to consider the impact of low graduation in regulation time. First, there are the psychological costs of failure to consider, as well as the financial implications of this (many students forfeit their bursaries if they fail a year). Second, there is the curriculum incoherence that results from failure, when students repeat subjects which clash with current courses. In fact, as the statistics indicate, curriculum coherence exists ironically only for the *minority* of students who complete in minimum time.

So, in summary, the statistics on retention and graduation in minimum time indicate that higher education is currently set up for a minority of students. This requires a response from higher education.

Option 2: Higher education needs to respond

The statistics suggest that the problems in higher education are essentially systemic, and addressing them therefore calls for *structural* rather than peripheral or *'remedial'* responses (Scott *et al.*, 2007). This argument is not new, but dates from the debates concerning academic development in the 1980s and 1990s. Here, the dominant 'deficit' model, whereby students need to be 'fixed' by foundation/add-on courses, was critiqued in favour of more structural responses which argued that the university itself needed to change its mainstream teaching practices and institutional culture (Boughey, 2007). The implication of this for higher education now is that we need to rethink our curriculum structures and teaching approaches. Extended curriculum programmes may need to become the norm, with an 'accelerated' stream on offer for some students.

However, extending the time of the degree alone is not sufficient; it is crucial to look at the design and pedagogy of the curriculum itself. In South Africa, foundational programmes and provision have a long history, with different approaches adopted over the years (Kloot *et al.*, 2008). The earliest programmes adopted a 'more time, more tuition' approach, with the regular course taught over a longer time period, often with some extra tutorial support included. However, this approach was subsequently found to be limited – more of the same was not what was required. The next approach was to keep the mainstream courses the same, and to add 'skills courses' (such as English, computer skills, life skills). However, research on the impact of add-on skills courses, as well as contemporary theories of learning, point to the limitations of this approach. The trend nowadays is towards an integration or infusion of foundational provision into the discipline courses themselves.

Curriculum design, teaching and learning implications

In designing new curricula, it is important that these are based on research and scholarship. In a recent analysis of the DoE funding applications for extended curriculum programmes (ECPs), it was found that many of these curricula were not designed in a scholarly, research-based manner (Boughey, 2008). This was despite the substantial

[12] Even within competitive-entry programmes at elite HEIs in South Africa, often only about 25–30% of students complete in minimum time.

South African and international research on the limitations of 'add-on' skills courses, as well as the substantial international and South African literature on STEM undergraduate education reforms.

A socio-cultural perspective on learning

If curricula are to be more scholarly and research-based in their design, what are the theoretical bases we can draw on? Historically, science and mathematics education have been dominated by individual or cognitivist perspectives on learning (Ausubel, 1968). These have focused on knowledge acquisition, mental models, 'misconceptions' and conceptual change (for example, Posner *et al*., 1982; McDermott, 1984). More recently,[13] there has been a shift towards more socio-cultural perspectives on STEM learning. Here, learning is viewed not just as a cognitive process, but as a process of identity formation through accessing a disciplinary discourse[14] and increased participation in the activities of a community (Brown, Collins & Duguid, 1989; Lave & Wenger, 1991). It is important to emphasis that these two perspectives on learning are complementary rather than mutually exclusive (Leach & Scott, 2003; Sfard, 1998).

In undergraduate STEM education, new curricula are being designed taking into account these socio-cultural perspectives on learning. There is a move from traditional lectures towards creating classroom communities focused on interactive engagement.[15] A socio-cultural perspective on learning also implies a focus on participation in activities that mirror the practices of scientists, for example, a move towards investigation-based first-year laboratories[16] rather than the more traditional 'cookbook'-style laboratories (this is also reflected in the emphasis of the new NSC physical science curriculum on investigation and experimental design). There tends to be a focus on authentic activities and problem-based learning as well as involving undergraduates in research projects from their first year (for example, Schroeder, 2010).

A socio-cultural perspective on learning also implies making explicit to students the discourse (Gee, 1999) of the STEM discipline (in other words, the way the discipline represents itself, as well as the values, ways of thinking and processes of enquiry particular to that discipline). For example, Airey & Linder (2009) characterised physics learning in terms of developing fluency in the disciplinary discourse of physics. Helping students to access the disciplinary discourse, and develop fluency within it, may be supported through collaboration between academic literacy practitioners and disciplinary lecturers (Jacobs, 2007). For an example of an undergraduate curriculum framed around learning as accessing a disciplinary discourse, see Marshall & Case (2010).

13 First in mathematics education, and more recently in science education.

14 'Discourse' refers to the way in which a discipline represents itself – not just in words, but in graphs, symbols, how its artefacts are used, as well as the value commitments that underlie these representations; the ways of thinking, acting and valuing of that discipline (see, for example, Gee, 1999).

15 For examples within a wide range of undergraduate STEM disciplines, see Peer Instruction at Harvard and elsewhere (Mazur, 1997); the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programmes) project at MIT and elsewhere; in South Africa, the Science Foundation Programme at the University of Natal in the early 1990s (Grayson, 1996).

16 For example, the Investigation-based Science Learning Environments (ISLE) project (Etkina & Van Heuvelen, 2007), framed within a situated cognition perspective.

Finally, taking on a disciplinary discourse and participating in community implies that learning is not just a cognitive process but a process of identity formation on the part of the student. It is important that students are not just exposed to the dominant identity of researcher/academic, as modelled in the classroom, but that they are also exposed to a range of possible identities and roles they could take on one day, as an engineer, chemist, mathematician, and so on, that may accord with their own interests, motivations and aspirations. For a South African example of a socio-cultural perspective on undergraduate STEM curricula, see Allie *et al*. (2009).

A socio-cultural view of learning has implications for where responsibility for curriculum reform lies. If learning is viewed as a process of increased participation in a disciplinary community of practice, then it stands to reason that those best suited to inducting newcomers into that community of practice are the practitioners of the discipline themselves. This implies the need for 'whole department' commitment to curriculum reform, rather than having separate, add-on courses taught by marginalised contract staff. This will require educational expertise in the department: individuals who can lead educational innovation and mobilise other sympathetic staff members to take an interest in curriculum renewal.[17] However, in contrast to this model, the advent of the DoE ECP funding has seen the creation of numerous ECPs in HEIs, many of which are taught by marginalised contract staff.[18] From a socio-cultural perspective on learning, this is not the most productive model to adopt.

Reasons for resistance to curriculum reform and extended degrees

There are a number of reasons for resistance to undergraduate curriculum reform and the introduction of extended curriculum programmes, including the following:

What matters in HE: research *vs* teaching

In their CHE study, Scott *et al*. (2007) argue that for curriculum reform to be effective and for extended curricula to be introduced, educational expertise is crucial. However, educational expertise can only be developed in a context in which teaching and learning are valued and rewarded. For example, sociologically framed research by Kloot (2009) in the context of engineering foundation programmes demonstrates how, in a context in which research is valued over teaching and learning, institutional change and curriculum reform may be constrained. In line with international trends, there is a need for South African higher education to move beyond dichotomising research and teaching, and instead look towards the international focus on the scholarship of teaching and learning (Boyer, 1998).

[17] This will take on different forms depending on the institutional culture. For example, at the University of Cape Town, there has long been the structure of having academic development discipline experts located within departments.

[18] The University of the Western Cape (UWC) Physics Department has resisted this model of foundational provision, and has instead attempted to adopt the 'whole department' approach (Holtman & Marshall, 2008). Since the inception of the ECP in 2007, half the staff members of the UWC Physics Department have been involved in teaching in the ECP courses. This had led to a critical mass of lecturers involved in undergraduate curriculum reform. This has also had some ripple effects on the second-year curriculum.

Fears about 'falling standards'

In some quarters, mathematics and science undergraduate curriculum reform is equated with 'dumbing down'. There is resistance to changing existing teaching approaches or curricula in the name of maintaining standards, yet ironically the teaching approaches and curricula being maintained are often, in fact, outmoded and out of touch with current practices elsewhere. For example, physics at MIT is no longer taught in traditional large lectures but rather in flat-venue, interactive-engagement classroom communities. Similarly, there may be resistance to changing the content of traditional undergraduate courses, often seen as a 'canon' not to be challenged. Yet, several recent curriculum reforms have led to substantial changes to standard curricula (for example, the Harvard Calculus Reform Movement, or reframed undergraduate physics curricula).

I have chosen to refer to curricular reforms at Harvard and MIT in order to emphasise that curricular reforms worldwide are introduced not because students are underprepared or weak, but because these are based on research which highlights how students learn best.[19] Curriculum reforms therefore benefit *all* students, not only those deemed underprepared. In other words, they not only improve the pass rate, but also the top A-grade students become better students.

Concerns about financial implications

The third reason for resistance to curriculum reform centres on concerns about financial implications: many consider that curricular reform, and especially making extended degrees the norm, are just too costly. However, for *the state*, the current throughput statistics reveal a very inefficient system, and very poor returns on investment. It is not hard to imagine that initial investment in extending the regulation time to graduate might, in the long run, lead to better returns on investment in the form of better throughput and retention rates. For *students and their communities*, more responsive curriculum structures would lead to better throughput rates, less drop-out or financially unplanned years in higher education. For *universities*, it could be hoped that the Department of Higher Education and Training's greater focus on output subsidies would induce universities to invest in extended curriculum programmes and improving teaching and learning, with the intention of improving their retention and throughput, and hence increasing the output subsidies generated.

So far, this paper has argued for curricula that are responsive to students' needs. However, there is also a need for curricula to respond to the needs of the 21st century, for example, climate change, social justice, food security, democracy and sustainability of financial systems.

New curricula to address the challenges of the 21st century

Curricular reforms and extended curriculum programmes are needed not merely to teach what we currently teach better. New curricula and extended degrees may also provide the curriculum space[20] to incorporate new dimensions into undergraduate courses.

[19] For example, there are now many STEM education research groups in North American universities; one at the University of British Columbia is headed by Physics Nobel laureate Carl Wieman.

[20] This is a term Ian Scott uses (Scott *et al*. 2007), in contrast to seeing ECPs merely in terms of "more time".

We need to be producing creative, innovative thinkers. Currently, there is much concern about the high failure rates in first-year mathematics and physics courses, yet decades of science education research show that so-called 'successful' students in such courses often emerge with very little deep understanding or ability to apply their knowledge to wider contexts. In order to produce graduates who can apply their knowledge in creative and innovative ways, we will need to produce different sorts of students.

We need to be producing science and engineering graduates that are committed to social justice and democracy, and who can see their disciplines in a wider context – not just in terms of technical 'know-how' but in terms of the wider societal and environmental implications. For example, the Soudien report on racism at South African HEIs (Soudien *et al*., 2008) revealed that there is much work to be done in terms of diversity and tolerance within our student populations. We need to address these issues in our curricula and in our classroom practices, and not just in the broader discussion about institutional culture (see Jansen, 2009). Walker *et al.* (2009) argue for the need to produce "public-good professional capabilities" in our graduates.

We need to be producing graduates able to work in a range of contexts. In the past, universities have tended to produce graduates for corporate capital, particularly engineers for the mining and petrochemical industries. However, we now require science and engineering graduates who will be able to contribute to the fields of renewable energy, climate change, new economic systems, social development, and so on.

In responding to 21st century needs, we are likely also to be responding to the concerns and aspirations of many of our students. For example, some students choose engineering because of their concerns related to social and environmental issues (Jawitz & Case, 1998); some very good engineering students become alienated from their studies because the curriculum does not explicitly address such issues (Case, 2007). Undergraduate curricula that encompass new dimensions may attract a wider range of talented students to undergraduate STEM studies.[21] Perhaps, rather than raising entrance requirements to attract 'better students' into science and engineering, we would attract better students by making the curricula more attractive to a wider pool of students.

In summary, what needs to change in higher education?

- We need to rethink the *entire* degree structure. If the extended degree becomes the norm, this will require redesigning the curriculum throughout, not just adding on an extra year at the outset.

- At first-year level, we need to start where students are, not where we think they '*ought*' to be.

[21] For example, Tobias' USA research (Tobias, 1990) found that many talented students were put off first-year physics by the narrow, decontextualised manner in which it was taught.

- Curricula need to be designed in a scholarly way, taking into account research on STEM teaching and learning. South Africa is not the first country to undergo massification of higher education, and we can learn from how other countries have addressed this.

- We need to build on the strengths of the NSC – students enter higher education after completing a curriculum that stresses relevance, social contexts of STEM, and which is investigation-based. Our first-year curricula need to take this into account.[22]

- We need to respond to our students' strengths (their interest in wider contexts of science, their tendency to be more interactive and technology-oriented, etc.) and their aspirations.

- The scholarship of teaching and learning (SoTL) needs to be a key focus in HEIs. This will require institutional support, both financially and in terms of what is valued and rewarded.

- We need to rethink 'growth' models in higher education. Many HEIs feel the imperative to grow, but we need to think of growth not only in terms of increasing first-year intakes but in terms of improving throughput and retention.

- We need to conduct rigorous and scholarly investigations into the nature of the 'gap' and how best higher education might take on the role of 'minding the gap'.

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[22] For example, the NSC physical science curriculum has a more conceptual focus than previous curricula, yet traditional Physics 1 courses may be experienced as rewarding memorising equations and algorithmic problem-solving, Moreover, in the NSC, context and relevance are stressed, whereas traditional first-year courses may seem very abstract and decontextualised. The NSC emphasises scientific investigations, yet traditional first-year practicals tend to follow a 'cookbook'-type format.

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DISCUSSION

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Most of the discussion centred around the following points:

- responsibility for closing or facilitating navigation of the gap between school and university;
- interactions between schools and universities;
- tensions between teaching and research demands for university lecturers;
- issues related to extending the length of the bachelors degree.

There was also some discussion about the discontinuity between assessment at school and at university, which may be damaging to students who are used to doing well at school and then do poorly at university. One of the delegates commented:

I would like to respond to the comment that the best approach is to meet students where they are and to teach them accordingly, and not just blame the school system. I believe that there is an element of the problem that is a joint problem. I am not referring to a lack of content knowledge but to the emotional damage of failure. We find that students come into higher education with a self-concept that was formed through inadequate feedback on what they do not know. They often have unjustifiably high expectations and expect to do so much better than they actually do. They do not respond in time to feedback from assessments, because it does not fit the assessment they received at school, where they were possibly the top of the class in a small school. They may suffer from gross overconfidence. In that sense, I hold the school system accountable for the fact that school assessment failed to give learners a more realistic perspective of what they know and where they are lacking.

Responsibility for closing or navigating the gap

Comment: I am in agreement that there has to be collective responsibility, but I do not believe that the Department of Education can renege on its responsibility. In an ideal situation, what has been proposed would work well, but there are schools that are in a dismal state.

Prof. Marshall: On the issue of whose responsibility it is, I was talking from the perspective of science and mathematics undergraduate lecturers. Obviously schools have to take responsibility too. My argument was that undergraduate lecturers should consider what they can do to address the situation from within the ambit of higher education, since they cannot influence what happens in schools. Teacher education would be one way of having an effect. I was arguing against the dominant response of higher education that schools should get their act in order and HEIs will remain unchanged, as well as too often clinging to outmoded approaches. Obviously the initiatives have to be two-pronged.

Comment: When learners fail at school, we blame the teacher, but when students fail at university, we blame the students and their school teachers, not ourselves. Society is listening to university vice-chancellors complain that students are failing and underprepared, but HEIs are not taking responsibility for the quality of teaching and learning at universities. I am not saying there are no problems in basic education, but teaching is difficult, at universities as well as at high schools. How do we move the discourse from where we are, blaming teachers?

Prof. Marshall: I agree that we need to change the discourse. I felt very uncomfortable about the National Benchmark Test and the hype that the results generated, whereas the results were hardly surprising. I do not have an answer, but believe we should take note of what is happening in the rest of the world and take a scholarly approach to what we are asking of undergraduate teachers in order to remain abreast of international trends.

Comment: Higher education cannot simply say the problem lies with schools and learners; higher education also has a responsibility to invest in the scholarship of teaching and learning and to take a scholarly approach to lecturing, not just to regard it as an obligation that we must get out of the way so that we can get on with research. Teaching and learning should be an area for research, reflective practice and scholarly development.

Comment: It is inevitable that there will be a gap between school and university, since these are different institutions that do things differently. The issue is whether that gap is bigger in South Africa than in other countries, because we do not see the social fabric that navigates that gap in other societies. If 50–60% of school-leavers continue to higher education in developed countries that means that those countries have a far bigger middle class where the fabric is part of society and navigation of the gap is supported by many other practices. We do not have much of that and expect a lot of both the university and the school in 'minding that gap'. Being smart also means identifying other ways of navigating the gap and making the transition smoother for more students.

Comment: The purpose of this Forum is to take responsibility for the problems we discuss and co-construct a way forward. We recognise that the boat is leaking, but should not be asking, 'Whose side it is leaking on?' We must be careful of the messages we send. It is a historical problem for scientists and mathematicians to complain that educators do not involve them in the discussion; they cannot say that they do not want to become involved in science education work because they want to pursue their blue sky research. We have to re-commit to working on this together.

School–university interaction

Comment: An interesting conversation has recently started in the Gauteng Department of Education about the development of the talent pipeline. Schools and the department recognise the gap between school and university and acknowledge that they are partly responsible. They have committed themselves to finding ways of fixing it. One of the biggest challenges is that the school system cannot invent something that will only benefit those that go to university, so the whole school system has to be geared to fixing the whole school system.

The concept of the talent pipeline involves trying to identify the population of learners that will go on to university as early as possible – grade 8 or 9 or even before then – and for the school system to put in place a parallel preparation programme to assist in decreasing the size of the gap, as least from the school side.

The discussions are at an early stage and have not yet become policy, but the intentions are serious to the extent that investing money in the scheme is being proposed. The idea is to set up programmes within each of the 15 education districts of Gauteng at which learners would be gathered together and offered additional extramural activities. This would not just be life skills and study skills, but might introduce them to content they will encounter at university so that it becomes more familiar as well as introducing them to the different culture they will be exposed to when they leave school – whether in education, training or the world of work.

The discussion is moving ahead, but local universities have not yet been brought in. I invite universities to become involved in the debate to address the gap from both sides. There will always be a gap between university and school, and perhaps there always should be, but it ought to be possible to navigate it.

Comment: In our work with schools, particularly those that are doing well in terms of producing good mathematics and science passes, when we ask teachers what they are doing to achieve that, we often get the response that the schools work hard to get local university people to come to schools or to take learners to universities. I wonder how many lecturers know their local schools in a formal way, backed by energy and intent, and how much interaction they have with teachers there in order to close the gap so that learners know more about the university before they arrive there.

At a pragmatic level, university requirements are complicated. Many schools leave it to learners to figure out what entrance requirements are needed for which courses. Abbotts College has produced a very useful guide of all the universities and the entrance requirements for their key courses. Universities could assist schools with practical information of that nature.

Tensions between teaching and research demands for university lecturers

Comment: Universities are also not all at the same level. Rural-based universities tend to be in really bad shape. There is always tension between research and teaching, and at universities, each member of a department is required to produce 1.25 research units per year. At some universities, that target is impossible to achieve, yet staff are still pushed to do so. We need to be realistic in what we want to do.

Prof. Marshall: In response to the comment that under-funded rural universities nevertheless have an imperative to publish and that a four-year undergraduate programme would impose an even greater financial burden, I believe that the four-year degree programme will require investment by the state. I also believe that we must move away from the dichotomy between teaching and learning and recognise that an aspect of being a scholar is to be scholarly about one's teaching. The international trend is to move away from that dichotomy.

Comment: If we are to take this discussion forward, we need to ask the hard questions. The Department of Physics at the University of the Western Cape (UWC) has departed from the model and tried to equip more lecturers. How has this impacted on the research output of the department? This touches on the pressures that lecturers are under. Those doing scientific research, as opposed to education research, might also be involved in the scholarship of teaching and learning, but that is not our primary research activity. Scientific research is very demanding. It seems that we are beginning to ask the impossible from an academic. For those doing scientific research and having to maintain academic standards of keeping up with their discipline internationally, research on learning is not primary. Is there a department in the country that has managed to do this in any discipline?

Prof. Marshall: SoTL does not imply that lecturers have to engage in research. Eric Mazur, who pioneered many of the interactive approaches at Harvard, had a research interest as well, and Wiemann was a Nobel laureate, so SoTL and scientific research are not mutually exclusive. In our Department of Physics at UWC, everyone has a teaching load. What we have done with respect to teaching the four-year programme has been to ensure that a critical mass of lecturers was involved. This did not mean spending time developing the curriculum but simply being involved in teaching some part of it and becoming caught up in the energy of the core staff for whom it was a focus. This did not increase their teaching load but simply entailed strategic redistribution of that load. Involvement in the new thinking sometimes led to changes in the way lecturers taught second- and third-year courses, as they became interested in the way in which the mainstream course and the extended four-year programme interacted.

Comment: Experience shows that departments in which there is curriculum innovation usually have the strongest researchers. Teaching and research reinforce each other rather than detracting from research. I am not talking about a situation in which the teaching load is so heavy that there is no time to do anything else, but where there are capacity and resources. We find the most innovative teaching is done by active researchers who take a scholarly approach to the work they do. I do not believe that teaching and research are antithetical; however, there is a point at which teaching can become onerous and there is no time to do research.

Comment: It should be recognised that Prof. Marshall is a very valuable resource in her department. In this country, we are fortunate to have people in scientific departments who focus on educational expertise and feed this into discussions. It is crucial that they are disciplinary persons themselves. Prof. Marshall plays an enormous leadership role; her colleagues have not had to scan physics education journals and make sense of the content themselves. She has often led much of that thinking and worked with them. Departments also use academic literacy people and language specialists working alongside them.

Issues around extending the length of the degree

Comment: I would be in favour of a four-year BSc degree (which is about the same as adding a 13th year to school, since both approaches would result in an extra year spent in the education system). I was under the impression that staff employed for the foundation programme should work only on that and not on any other work of the department. I would like clarity on that.

Prof. Marshall: I believe that a 13th year at school and the four-year degree programme are different. The four-year programme would entail rethinking the design of the whole degree, rather than just adding an extra year, as well as ensuring that contemporary approaches are infused into teaching and learning throughout the programme. Moreover, the commitment of the whole department to reform would be required. This approach extends far beyond a remedial fix in the first year.

On the issue of teaching staff for the four-year programme, pragmatically, the faculty at my university opted as a general approach to use marginalised contract lecturers on the side. However, the Department of Physics chose to use the funding that could have been put towards contract staff in order to enable many mainstream senior lecturers to teach on the four-year programme, thus cross-subsidising the programme by the department. I explained how this was justified in terms of theories of learning on the grounds that mainstream academics are needed to induct learners into the community of learning. I believe that using marginalised contract workers to lecture on the side is very dangerous.

Comment: The reservations on the funding implications of changing a three-year degree to a four-year degree are not new. Foundation programmes and other technologies outside the mainstream have been grappling with this since the early years of academic support programmes. We would have to get money from outside the university, since government has not changed the funding formula to recognise this as a mainstream activity that needs to be funded as such. The proposal to fund such activities has been made to government before without success. Extended curriculum programmes need to be funded like any other year in the programme in order to realistically attain the goal.

Comment: I believe that the funding formula is an example of the 'tail wagging the dog'. Many aspects of the education system are very rigid, and we keep trying to impose a 'one size fits all' solution on a very diverse society with diverse needs. In the USA, a basic BSc can take anything between three and five years, depending on an individual student's level of preparation. If the funding formula is a problem, why not change it?

Chapter 6: STEM and the language of instruction

MATHEMATICS IN MULTILINGUAL CLASSROOMS: FROM UNDERSTANDING THE PROBLEM TO EXPLORING POSSIBILITIES

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Introduction

In 1998 I started a research programme focusing on mathematics education in multilingual classrooms in South Africa. The main problem that triggered the initiation of the research programme had to do with my concern about the low mathematics performance of a majority of learners in multilingual classrooms in South Africa who learn in a language that is not their home language. At the core of this concern is a need to address the uneven distribution of mathematical knowledge and success. It is now ten years since I started the programme, and I have video-recorded, transcribed and analysed 60 primary and 70 secondary mathematics lessons in 16 mathematics classrooms in Gauteng, North-West and Limpopo provinces in which both teachers and learners are multilingual and none has English as their home language. I have also held over 30 hours of individual and group interview sessions with selected teachers and learners in these schools.

The purpose of this paper is to give a brief description of my personal journey from understanding the problem to exploring possibilities. The plural word 'possibilities' is used in the title to suggest the fact that given the range of multilingual contexts in South Africa and elsewhere in the world, there cannot be just one possible solution to the problem. This paper provides a description of this journey and, in so doing, highlights the contribution made to research and practice in the area of multilingualism and mathematics education as well as the challenges that lie ahead in this area of study.

Understanding the problem

While the concern about the mathematics performance of learners in multilingual classrooms in South Africa served as motivation for this project, investigating the impact of multilingualism on learner performance is complex. Learner performance is not determined by language proficiency alone, but by a complex set of interrelated factors that range from the pedagogic issues specific to mathematics to the wider social, cultural and political factors that infuse schooling. So while proficiency in the language of learning and teaching (LoLT) is one of the factors that may impact on learner performance, it is not the only factor. As Barwell (2009) argues, even research that shows learner performance as having some connection with proficiency in the language of learning and teaching (for example, Howie, 2003a) is never clear about whether the differences are a result of linguistic, cultural, social or economic conditions or some combination of these and other factors. My research thus started with developing an understanding of the problem of poor learner performance in multilingual mathematics classrooms before exploring possibilities.

Language is important for learning and thinking, and the ability to communicate mathematically is central to learning and teaching school mathematics. The relationship between language and mathematics learning, however, takes on a specific significance in multilingual classrooms in which students learn mathematics in a language in which they are not fluent. Mathematics teachers in such classrooms have the dual task of continuously having both to teach mathematics and simultaneously to develop learners' fluency in the language of learning and teaching. Learners, for their part, have to cope with the new language of mathematics as well as the new language in which mathematics is taught (English). Thus learning and teaching mathematics in multilingual classrooms involves managing the interaction between formal and informal mathematics language, procedural and conceptual discourses, ordinary language and mathematical language, and home language and the LoLT.

Formal mathematics language is about acting-interacting-thinking-speaking-reading-writing in mathematically appropriate ways, which enables understanding across the wider mathematics community. Informal language is what is used in everyday interactions to communicate mathematical ideas. Both formal and informal mathematics languages are carried by distinctive mathematics discourses. Of relevance to this chapter are procedural and conceptual discourses. Procedural discourses are interactions that focus on the procedural steps taken to solve a problem. Conceptual discourses are interactions in which the reasons for calculating in particular ways and using particular procedures to solve a mathematical problem become explicit topics of conversations.

Doing mathematics involves an ability to engage in both procedural and conceptual discourses. Furthermore, mathematics teaching and learning occurs in a mixture of ordinary language and mathematical language. According to Pimm (1987: 88), learners' failure to distinguish between the two can result in breakdowns in communication. In a multilingual classroom of English language learners, the confusion between ordinary English and mathematical English is complicated by the fact that both languages are new to the learners.

Analysing empirical data to understand the problem

Analysis of the lesson observation data collected from 1998 to 2003 with the purpose of understanding the problem showed a dominance of English and the use of procedural discourse. The dominance of English was evident in the interactions between learners as well as with the teacher. The fact that the interactions were in English was not the only thing that characterised the interactions, but also the fact that they were abbreviated and procedural (see Setati, 2005). Procedural discourse was evident in the mathematics tasks and tests that the teachers gave learners, as well as in the interactions that occurred during the observed lessons, which suggested that conceptual discourse was not regarded as valued mathematical knowledge.

The analysis also showed that teachers were giving learners low cognitive level demand tasks, which either required the use of "procedures without connections" (Stein *et al.*, 2000) or were not at the required level for the grade. Mathematics tasks and tests given to learners inevitably communicate to learners what is valuable mathematical knowledge. Thus the absence of high cognitive level demand tasks that require fluency in conceptual discourse in the lessons observed was seen as a weakness.

The learners' lack of exposure to high cognitive level demand mathematics tasks as well as the dominance of English despite learners' limited fluency in it, accompanied by the prevalence of procedural discourse, raised the following question: 'What shapes the nature of the mathematics tasks and the language choices made in these classrooms?' At the heart of this question was an apparent disjuncture between what research and policy recommends and the practices observed in the classrooms. While research and policy encourage multilingualism as well as language practices such as code-switching as resources for learning and teaching in multilingual classrooms, the data indicated the dominance of English. To understand this apparent disjuncture, it was important to explore through individual interviews with teachers and learners the language(s) they prefer for teaching and learning mathematics and to consider how these shape the nature of the mathematics tasks selected and interactions in these classrooms.

First and foremost, the analysis showed that English as an international language was the dominant discourse that shaped the teachers' and learners' language choices. All of the six teachers interviewed stated ideological and pragmatic reasons for their preference for teaching mathematics in English (see Setati, 2008). Both teachers and learners are aware of the linguistic capital of English and the symbolic power it bestows upon those who can communicate in it. All the teachers used similar terms when referring to English as an international or universal language. Awarding such a status to English suggests that they consider English as being 'bigger than' themselves. They do not have any control over the international nature of English. All they can do is to prepare their learners for participation in the international world, and teaching mathematics in English is an important part of this preparation. All the reasons that the teachers gave for their preference for English were unrelated to mathematics learning, but were about the need to ensure that learners can gain access to the social goods that fluency in English makes available. A glaring absence was any reference to how their preference for learning and teaching in English would promote their learners' access to mathematics knowledge and success. The teachers regarded teaching mathematics in English in these multilingual classrooms as another opportunity for learners to gain access to English. Their explanations for their preferred language(s) for mathematics teaching focused on English and not mathematics. These teachers positioned themselves in relation to English (and thus socio-economic access) rather than to mathematics (in other words, epistemological access).

While there were conflicting discourses in the learners' views, it was clear that the majority of learners expressed their preference to be taught mathematics in English. For these learners, learning mathematics in English is not so much about choice; it is just 'how things should be'. They thought it unimaginable for mathematics to be taught in an African language. Among the their reasons for wanting to be taught in English were the fact that mathematics textbooks and examinations are in English, university lecturers and job interviews are only in English, and communication with 'white people' is in English. All this contributed to the discourse that without fluency in English, they would not have access to all these important social goods. These findings suggest that, like teachers, these learners saw mathematics learning as another opportunity for gaining fluency in English. This was the case even for the two out of the ten learners interviewed who indicated that for them it does not really matter which language is used for teaching and learning, because mathematics is a language on its own.

Despite the overwhelming discourse that foregrounds the hegemony of English and the need to gain access to social goods that English makes accessible, there are differences in the manner in which different learners positioned themselves. The two learners who explicitly indicated that it does not really matter which language mathematics is taught in positioned themselves in relation to mathematics. Their language preferences were connected to gaining proficiency in mathematics rather than to gaining fluency in English. The rest of the learners positioned themselves in relation to English in the sense that they were more concerned with gaining fluency in English so that they could access social goods such as jobs and higher education. Their desire to gain fluency in English was not connected with improving their mathematics learning but with access to social goods. As a result, they saw mathematics teaching and learning in multilingual classrooms as an opportunity to gain fluency in English.

What does this mean for research, policy and practice?

The preceding discussion indicates that decisions about which language to use in multilingual mathematics classrooms, how, and for what purposes, are not only pedagogical but also political (Setati, 2005). This conclusion explains why recommendations emanating from policy and research are difficult to translate into practice in multilingual contexts such as South Africa. In terms of policy, there is an assumption embedded in the South African Language in Education Policy (LiEP), which promotes multilingualism and encourages the use of the learners' home languages, that mathematics teachers and learners in multilingual classrooms, together with their parents, are somehow free of economic, political and ideological constraints and pressures when they apparently freely opt for English as the LoLT. The LiEP seems to be taking a structuralist and positivist view of language, one that suggests that all languages can be free of cultural and political influences. Research, however, recommends the use of the learners' home languages and thus suggests that concerns about learners' access to mathematics precede concerns about access to social goods such as tertiary education and jobs. However, evidence from data in my research shows that calls for social access predominate over those for epistemological access. Most of the research in this area of study is framed by a conception of mediated learning, where language is seen as a tool for thinking and communicating. While it appropriately foregrounds the mathematics, it does not consider the political role of language. There is thus a need for research in this area of study to recognise and acknowledge language as political. Without such recognition, we will fail to understand and work with the demands that teachers and learners in multilingual classrooms face.

As explained earlier, lesson observation data in this study highlighted the dominance of English and procedural discourse in these multilingual classrooms. Other researchers have interpreted this dominance of procedural teaching as a function of the teachers' lack of or limited knowledge of mathematics (Taylor & Vinjevold, 1999). The foregoing analysis and discussion suggest that the problem is far more complex. There seems to be a tension between the desire to gain access to English and the important, but not always recognised and acknowledged, need to gain access to mathematical knowledge.

The analysis and discussion have suggested that possibilities for solving the problem should be considered by exploring ways of drawing on learners' home languages while ensuring that they gain fluency in English. This calls for the need to consider the learners' home languages as a resource for teaching and learning. The challenge, however, is that in a context such as South Africa, where the hegemony of English is so prevalent, regarding the learners' home languages as a resource tends to be seen as a threat to multilingual learners' development of fluency in English. As Sachs pointed out (1994: 1), in South Africa "all language rights are rights against English". Hence my argument that for the use of the learners' home languages in the teaching and learning of mathematics in multilingual classrooms to be successful, it must be done in such a way that it ensures that learners gain epistemological access without losing access to English. Granville *et al.* (1998) present a similar idea in relation to the South African Language in Education Policy, where they argue for English without g(u)ilt. What is new about the proposed use of language(s) in exploring possibilities in this paper is the different orientation it brings by focusing on learning and teaching rather than on policy.

Exploring possibilities

Debates in research and in the public domain on language and mathematics teaching and learning in multilingual classrooms tend to create dichotomies of language choices and theoretical perspectives. These dichotomies create the impression that using learners' home languages for teaching and learning must necessarily exclude and stand in opposition to English, and that developing learners' mathematical proficiency must necessarily stand in opposition to developing fluency in English. Furthermore, these dichotomies create the impression that conducting research that is informed by a socio-political perspective should necessarily exclude and stand in opposition to cognitively oriented research.

In an article entitled 'Why don't kids learn maths and science successfully?' published in the *Science in Africa* magazine in 2003, Sarah Howie of the University of Pretoria argued that the most significant factor in learning mathematics is not whether the learners are rich or poor. It is whether they are fluent in English. She insisted, "Let's stop sitting on the fence and make a hard decision. We must either shore up the mother tongue teaching of maths and sciences, or switch completely to English if we want to succeed" (Howie, 2003b). She made this argument drawing on her analysis of South Africa's poor performance in the Trends in International Mathematics and Science Study (TIMSS) of 1995 (see also Howie, 2003a). While Howie's downplaying of the effects of socio-economic class on mathematics education and achievement is problematic, of relevance here are her views about language choice and use in multilingual mathematics classrooms. In the light of the preceding discussions, Howie's suggested solution to the problem is simplistic. Multilingual learners ought to be viewed in a holistic manner, which is different from Howie's monolingual view. Multilingual learners have a unique and specific language configuration and therefore they should not be considered as the sum of two or more complete or incomplete monolinguals. The possibility explored in this paper is informed by this holistic view of multilingual learners.

One of the lessons that emerged from the process of understanding the problem is the fact that separating cognitive matters from the socio-political issues relating to language and power when exploring the use of language(s) for teaching and learning mathematics in multilingual classrooms is not productive. While cognitively oriented research does not deal with the political role of language and the socio-political issues related to the context in which teaching and learning takes place, it is important to acknowledge that it attends to issues related to the quality of the mathematics and its teaching and learning in multilingual classrooms. In this exploration of the solution to the problem, it is thus important to work against these dichotomies, not only of language choices but also of theoretical perspectives.

The possibility explored is broadly informed by an understanding of language as "a transparent resource" (Lave & Wenger, 1991; Setati, Molefe & Langa, 2008). While the notion of transparency as used by Lave and Wenger is not usually applied to language as a resource or to learning in school, it is illuminating of language use in multilingual classrooms. Lave and Wenger (1991) argue that access to a practice relates to the dual visibility and invisibility of its resources.

For language in the classroom to be useful, it must be both visible and invisible: visible so that it is clearly seen and understood by all, and invisible in that when interacting with written texts and discussing mathematics, this use of language should not distract the learners' attention from the mathematical task under discussion but facilitate their mathematics learning. This idea is similar to the use of technology in mathematics learning. The technology needs to be visible so that learners can notice and use it. However, it also needs to be simultaneously invisible so that the learners' attention is focused on the mathematics problem that they are trying to solve. Like technology, language needs to be a transparent resource. As Lave and Wenger argue, the idea of the visibility and invisibility of a resource is not a dichotomous distinction; it is not about whether to focus on language or mathematics – it is about recognising that the two are intertwined and are constantly in complex interplay.

The possibility explored in this paper is a teaching strategy that recognises the complexity of teaching and learning mathematics in multilingual classrooms, where the challenges of developing learners' mathematical proficiency are intertwined with challenges of the learners' proficiency in English. This strategy is guided by two main principles:

1. First, it is the *deliberate* use of the learners' home languages. I emphasise the word 'deliberate', because with this strategy, the use of the learners' home languages is deliberate, proactive and strategic and not spontaneous and reactive as happens with code-switching. Learners are grouped into home languages and given tasks in two language versions: English and their home language. In this way they can draw on any of the languages as and when they need to. Doing this ensures that learners are given the language support they need while developing fluency in English.

2. Second, it is the selection of real-world, interesting and challenging mathematical tasks, through which learners would develop a different orientation towards mathematics than they had in the past and would be more motivated to study and use it (Gutstein, 2003). Many learners in multilingual classrooms in South Africa have what Gutstein (2003: 46) describes as, "the typical and well-documented disposition with which most mathematics teachers are familiar – mathematics as a rote-learned, decontextualised series of rules and procedures to memorise, regurgitate and not understand". In this exploration, we selected high cognitive level demand tasks (Stein *et al*., 2000) that present real-world problems that learners may find interesting and useful to engage with.

The mixture of English and the learners' home language was typical in interactions during all lessons observed. The unproblematic move between the learners' home languages and English without explicit negotiation between interactants is an indicator that language is functioning as a transparent resource. Whilst it is visible, it is also invisible enough to be used without distracting the learners' attention from the task. This invisibility of language as a mediating tool allows a focus on, and thus supports the visibility of, the mathematics that the learners are discussing (Lave & Wenger, 1991). At the same time, the visibility of language (through tasks given in two languages) is necessary for allowing its unproblematic invisible use. The learners did not focus on the languages used and what they were used for; they focused on communicating their mathematical meanings and understanding. This transparency of language enabled conceptual interactions between the learners and the teachers as well as among learners themselves. When learners were provided with the language support they need and allowed to use their home languages as legitimate languages of interaction together with English, learners' interactions were conceptual, focusing not only on the solution itself but also on why it is correct. They were not concerned about the correctness of their grammar in either of the languages, but more focused on gaining an understanding of the mathematics task at hand, with both language versions serving as a resource that they could draw on as and when they needed to (see Setati, 2008).

Concluding remarks: what is it that we still do not know?

A recent review of research on multilingualism in mathematics education in South Africa highlights the need for more research in this area of study (Setati, Chitera & Essien, 2009). This area of research is crucial not only because it is important for equity and access to mathematics for all, but also because a majority of learners in South Africa learn in a language that is not their first, main or home language. As indicated earlier, poor performance by multilingual learners cannot be attributed only to their limited proficiency in English. Research needs to identify other factors that interact with the fact that these learners have limited proficiency in the LoLT, which contributes to their poor performance. Research also needs to identify measures that can be taken to ensure success in multilingual mathematics classrooms. In this paper, I have argued that this is likely to require the linking of cognitive and socio-political perspectives, and the deliberate, proactive and strategic use of the learners' home language together with English in the teaching and learning of mathematics in multilingual classrooms. Much remains to be done.

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DISCUSSION

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In discussion, participants engaged robustly with the proposals put forward by Prof. Setati. This discussion allowed for clarification of some of the key elements of the proposed strategy to use language deliberately and transparently in the mathematics classroom.

Participants asked what would happen if there were many home languages in one classroom; Prof. Setati's strategy appeared to imply the use of a 'dominant' home language. This is most probably only a resourcing issue, since if texts presented in two languages (home language and English) are mainly there as resources for the learner, then there is no fundamental reason why texts might not be available in a number of different home languages. A related issue was a concern about the situation in which the teacher is not fluent in the home languages used by learners. One participant wondered how the teacher would be able to tell if the learners were 'on track'. Another delegate asserted that he had been in this very situation and that it was not at all problematic. The strategy is not about the exclusive use of the home language. It is all about the learners having both English and their home languages used in the presentation of tasks and thus more resources to support their learning.

Some participants had concerns about the quality of translations. Indeed, one participant recounted experiences of translating mathematics competitions where the translation into African languages was ultimately abandoned due to ongoing criticisms of the quality of translations. Prof. Setati noted that in the early stages of this research, there had been a focus on ensuring purist forms of translation, but with the development of the strategy towards additional resources, it had become less important to worry about this aspect, as the aim was not to develop a register in the learners' home languages. The strategy thus recommends that technical terms that learners already know and use should not be translated, as the problem that learners face is not the individual terms but language comprehension. Some delegates were concerned that there were some things that one says in the home language that cannot be translated; while others arguing from precisely the opposite perspective suggested that the home language might sometimes offer terminology that can greatly aid understanding.

A delegate asked whether more code-switching might be an equally effective and simpler strategy to implement. Prof. Setati pointed out the key difference between this strategy and that of code-switching: these are written texts (in two languages) for learners' use that do not cut into the time that the teacher has to focus on the mathematics. Unfortunately, code-switching is only in spoken form and thus does not offer the language support that the learners require when they have to solve a task written in English.

Some delegates questioned whether there were international comparisons that might be useful in this regard. Prof. Setati referred to a collaborative international study of which she was co-chair, which included work on immigrant learners in the USA who were provided with Spanish texts to supplement the English language mathematics classroom.

In closing, the delegates returned to a consideration of the nature of the key problem. Prof. Setati centred the focus on the learning of mathematics rather than the development of English fluency. She did, however, also assert that it is important to bear in mind that although studies show that learners who are learning mathematics in a language other than their home languages do struggle, this is not the only reason – socio-economic factors certainly play a significant role.

Chapter 7: Evaluation and benchmarking of curriculum

EVALUATION AND BENCHMARKING OF CURRICULA: DETERMINING STANDARDS FOR QUALIFICATIONS AND CURRICULA

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Umalusi

Liz Burroughs runs the Qualifications, Curriculum and Certification Unit at Umalusi. She presented the first part of the presentation.

The questions posed by ASSAf for the presentation were:

- What progress has been made in developing benchmarks and related tools?
- What approach has been selected for benchmarking and why?
- Who or what should South Africa be benchmarking against?
- What gaps or problems remain?

Umalusi is a statutory body established through legislation in 2001 to quality assure the standard of education in schools as well as adult basic education and training (ABET). While not mandated to conduct research, Umalusi nevertheless created a Research Unit, which has, since 2004, done research focused on understanding the nature and the standard of the South African Senior Certificate, and more recently the new National Senior Certificate.

The evaluation instrument developed by Umalusi evolved gradually over time. In 2004, research was conducted on four matriculation subjects, in the same qualification over time (Senior Certificate 1993 and 2004), to address the question of whether standards were dropping. The investigation looked at the examined curricula. There were no tools, but Umalusi suggested criteria and categories, which were used by the researchers to highlight the differences in cognitive demand and level of difficulty. In 2005, Umalusi undertook a school and college comparison of four subjects shared in common across two different qualifications – the old Senior Certificate and the new National Senior Certificate. Both the intended and examined curricula were investigated. There were guidelines this time for the evaluation of both the intended and examined curricula. In terms of the intended curriculum, evaluators were asked to describe the key concepts and procedures expressed in order to understand the relative standard of the various courses. In terms of the examined curriculum, the evaluation teams were asked to evaluate the level of difficulty of the questions or tasks in the examinations. In response to the questions asked, the teams developed a variety of subject-specific tools and scales in order to make judgements about the relative standard of the various courses and the extent to which they, in the opinion of the evaluators, prepared learners for higher education with regard to the levels of cognitive challenges in the examinations for each course.

Umalusi researchers suggested that there was a need to develop a single tool to be used across subject areas. And so, in 2007, the 'cognitive tool workshop' was held in order to develop a tool that could be used to analyse four gateway subjects – English, mathematics, physical sciences and biology/life sciences – and compare them among equivalent qualifications in four anglophone African countries, namely, South Africa, Kenya, Ghana and Zambia.

In 2008, Umalusi undertook the *Maintaining Standards* project. Six gateway subjects for the Senior Certificate (HG and SG) and the National Senior Certificate were compared. The curriculum analysis compared the NATED 550[23] syllabi and the National Curriculum Statements (NCS) for mathematics, geography, physical sciences, life sciences, English first additional language and mathematical literacy (which did not have a precedent in the Senior Certificate, but which was also compared to the mathematics curriculum). The underlying purpose of the comparison of the intended curricula was to establish their equivalence as the basis for setting comparable examinations (the examined curricula) across the two qualifications. The importance of establishing this comparability was to ensure continuity in standardisation processes between the old Senior Certificate examinations and the new National Senior Certificate, in the absence of any historical norm.

The evaluation instrument for the *Maintaining Standards* project was based on what had been learnt from the previous research, but with additional constraints, since the Umalusi committee responsible for standardisation required succinct answers to very specific questions. Teams with a variety of expertise worked on the project. The instrument was a detailed questionnaire in two parts, partly in MS Excel and partly in MS Word. The raw material comprised all the material Umalusi could find on the curricula and syllabi – the NATED 550 syllabi for HG and SG, examination guidelines, examination papers over a period of three years plus memoranda, the National Curriculum Statements for the subjects, Learning Programme Guidelines, Subject Assessment Guidelines, exemplar papers, 2008 examination papers and relevant educational policies. In the curriculum analysis, the following aspects were analysed (these were the major headings of the tool):

- Content specification and coverage, weighting and focus
- Skills specification, weighting and focus
- Text specifications (language group)
- Organising principle and coherence
- Sequence progression and pacing

[23] The NATED 550 reports were the syllabi/curricula which underpinned the subjects for the Senior Certificate.

- Aims, purpose, vision and outcomes
- Teaching approach and subject methodology
- Assessment guidance
- Availability, user-friendliness and use of curriculum documents
- Concluding tasks in order to address specific questions that Umalusi required with respect to standardisation

The content analysis entailed entering the following for each of the curricula on a spreadsheet:

- All the major content areas represented in the three curricula
- The apparent cognitive complexity level for each area/sub-area
- Examinable or non-examinable nature of content
- Content weighting: percentage of class time
- Content weighting: percentage of examination time
- Focus: discipline-specific, generic, life skill (as percentages)

The theoretical foundation of the tool is Bernstein's theory of pedagogy (1996), which has been operationalised over time by various groups of researchers working in various countries across the world. Umalusi's evaluation has been shaped by Bernstein's concepts of the framing of selection, sequencing and pacing. So, for example, selection was operationalised as the specification, weighting and foci of content and skills. The instrument evaluates what is included in the curriculum, as well as how it is to be achieved. Table 9 gives an example of the evaluation for physical science in terms of difficult (D), medium (M) and easy (E) content.

Table 9: Comparison of physical science curricula

Curriculum	Estimated no. of 45-minute teaching periods		% class time (Full curricula)			% class time (Examined curricula)		
	Full curriculum	Examinable curriculum	D	M	E	D	M	E
NATED 550 SG	241	119	34	57	9	37	53	10
NATED 550 HG	254	144	37	55	9	47	44	9
NCS 2008	368	162	38	49	13	43	48	9

For NATED 550 HG, the full physical science curriculum required, in the opinion of the evaluation team, teaching time of 254 45-minutes periods, whereas the examinable content required 144 periods for teaching. By comparison, the NSC 2008 required 368 teaching periods for the physical science curriculum, but only 162 periods to cover the examinable work, which is less than half of the intended curriculum. The report includes nuanced and succinct analyses of what the figures meant.

Training workshops were held on how to use the tools. The workshops also allowed time for teams to develop consensus on the use of the tool and their findings. A separate instrument for analysing and comparing the Senior Certificate and the National Senior Certificate examinations formed a companion evaluation on the actual level of difficulty and cognitive demand.

How useful has this benchmarking been?

The benchmarking has been essential in terms of the standardisation work of Umalusi. It has provided immediate information to inform Umalusi's Statistics Committee in its deliberations and decisions related to the 2008 NSC examinations. It has also provided a nuanced understanding of the similarities and differences between the substance of the Senior Certificate and that of the NSC. The findings differ among the teams. No matter how carefully the tool is developed, the demands of the subject being analysed will influence how the instrument is used.

It is perhaps worth adding that, although the Senior Certificate was used to benchmark the new National Senior Certificate, this was done because the standard of the older qualification was better known in the system rather than because it was being held up as being the superior qualification. Indeed, the comparison, which has given Umalusi a much more sophisticated understanding of both the qualifications, is intended to provide a means of strengthening and stabilising the new qualification as it beds down in the education system.

The 2009 *Maintaining Standards* initiative is using the same teams to analyse curricula associated with the qualifications offered by Cambridge International Examinations (CIE) and the International Baccalaureate, and so to benchmark the South African qualification. The evaluation instrument will be altered to answer new questions related to the subjects and qualifications being compared, but the approach to analysing and understanding concepts, such as depth and breadth of curriculum and cognitive demand and difficulty, will remain the same.

Emanuel Sibanda heads the Statistics, Statistical Information and Research Unit at Umalusi. He presented the second part of the presentation.

In some cases, South Africa underestimates how far it has come. In 2008, all grade 12 learners sat for the same examinations. In the past, there were ten national (centrally examined) subjects, but as from 2008, that number increased to 66. All learners write the same papers across the country. The Senior Certificate was considered to be a one-year qualification, whereas the NSC is a three-year qualification. One of the implications is that the curriculum for the NSC is covered in grades 10–12, and some of the topics that used to be covered in grade 12 under the Senior Certificate have now been moved to the work covered in grades 10 or 11 (for example, in life sciences). The previous Senior Certificate offered subjects at both standard grade (SG) and higher grade (HG) levels, and most of the learners offered subjects at SG level.

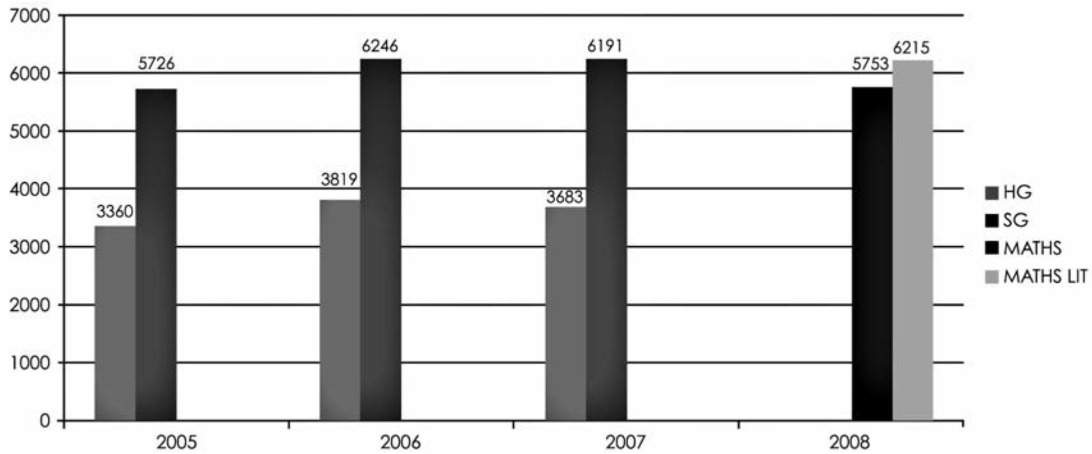
The NSC uses only one level, and all learners are expected to offer one form of mathematics, either mathematics or mathematical literacy. Table 10 shows the four-year average enrolment of learners in selected subjects before and after the introduction of the NSC. While there were overlaps between HG and SG subjects in the past, mathematics and mathematical literacy in the present NSC are two different subjects, which differ in kind.

Table 10: Enrolment in selected subjects before and after introduction of the NSC

Subjects	HG: 4-year average	SG: 4-year average	2008 NSC
Biology	80 945	189 581	206 338
English	383 342	10 563	323 423
Geography	89 392	97 039	147 644
Mathematics	29 578	213 613	201 602
Physical sciences	47 022	102 882	147 896
Mathematical literacy			196 617

Apart from English and geography, it is clear from Table 10 that the majority of learners offered SG subjects. About 30 000 learners offered mathematics at HG level in the past. In 2008, roughly 200 000 learners offered mathematics. From Table 10, it is evident that the majority of these learners are those who would have offered mathematics at SG level in the past. Prior to 2008, there were on average 3 500 and 6 000 schools offering mathematics at HG and SG levels, respectively. Some of the schools offered mathematics at both levels. Figure 5 shows the number of schools offering mathematical subjects in the old Senior Certificate and the new National Senior Certificate. This figure shows the increase in the number of schools that now offer some form of mathematics.

Figure 5: Number of schools offering mathematical subjects



According to Figure 5, in 2008, almost 6 000 schools offered mathematics. Again, this indicates that a number of schools that could have offered mathematics at SG level in the past opted for mathematics and not for mathematical literacy.

The purpose of the *Maintaining Standards* research was to provide Umalusi's Assessment and Statistics Committee with information on the comparability of the old NATED 550 and new National Curriculum Statement curricula, and on the comparative difficulty of the examinations associated with each one. This information will feed into Umalusi's *Indicators Project*. The indicators should provide a profile of the South African general and further education and training system, at a glance, and in context.

Conclusion

HEIs must understand where we come from and also the purpose of the NSC. The differences between the intended and the assessed curricula should be acknowledged, since teachers tend to focus on teaching the assessed curriculum. The comparison of the Senior Certificate and NSC will assist lecturers to understand what learners can be expected to know and the differences in the way that learners have been prepared for higher education, compared with cohorts from the past. In teaching first-year higher education students, HEIs should start where the students are, rather than assuming where they should be. In making comparisons, it should be borne in mind that some of the topics previously covered in grade 12 are now covered in grades 10 and 11. Once universities understand what their first-year students may lack, they can spend the first three months catching up. In assessing the results, it is important to bear in mind the profile of both learners and teachers.

It is necessary to identify indicators of quality standards and how to measure them. This will assist in defining where we want to be and ensure that we do not shift the goal posts or targets. Recommendations, particularly related to mathematics paper 3 and geography, must be informed by evidence-based research rather than anecdotal evidence.

Last, South African universities follow the same calendar as the schools. South Africa is the only country in SADC where the school-leaving examination results are released in December. In most SADC countries, this happens only in February or March of the following year, due to the time taken for the verification process, and universities starts in the second semester. Maybe we should consider this model, which would allow universities to use the first three months of the year for bridging courses. It is also important to recognise that releasing the South African matriculation results in December puts tremendous pressure on the processes of a body such as Umalusi.

References

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DISCUSSION

Fanie Terblanché

University of Pretoria

The majority of discussions centred on the following aspects:

- The differences between the old and new curricula and the number of teaching periods required to cover the syllabus
- The top 10% of performing schools.

Differences between the old and new curricula and teaching periods

Comment 1: In comparing the possible differences between what learners actually learnt under the old and new curricula, the opportunity was missed to conduct evidence-based research comparing the performance of first-year students in 2008 and 2009, since we have heard that first-year university curricula remained unchanged between 2008 and 2009. It is difficult to assess how demanding a curriculum is, and it may be easier to do so by looking at the examination paper than at the NSC. However, the level of demand of an examination question relies substantially on its degree of novelty for the learner. Did you take that into account?

Comment 2: Please clarify whether the teaching periods required to cover the syllabus were over one year or over three years. Also, were the hours required for the examined curriculum calculated according to what the DoE determined would be in the examination, or by looking at the demands in the examination paper?

Comment 3: Umalusi has extensively discussed the matter of needing more time for quality assurance of the results with the Minister, DoE and HESA, and a compromise position has been reached that Umalusi will provide the results by 31 December so that the Minister can officially release the results with a statement on 7 January.

Ms Burroughs: Umalusi has difficulties in getting into classrooms and doing evidence-based research. As a result of the statutory mandate and the relationship with the DoE, there are certain things that Umalusi is allowed to do and others that it is not. Our reason for conducting the investigation was that we believed that Umalusi could meaningfully contribute in terms of the intended and examined curricula. However, it would be difficult for Umalusi to observe how the actual curriculum is enacted because of the constraints.

Umalusi was not able to assess the performance of first-year students in 2009 and make comparisons with previous years due to both legal and financial constraints. However, Umalusi, in cooperation with the University of Cape Town, is doing a comparative analysis of a small sample from 2007 and 2008 using information response theory (IRT), which assesses ability at an item level. The results of the analyses will be compared with what expert evaluators told us in order to asses whether the predictions on what would be difficult and what would not are borne out by learners' performance.

The number of lessons required was indicated in terms of the Subject Assessment Guidelines and took only grade 12 into account. The NSC physical science curriculum is so extensive that teachers are hard-pressed to cover even just what they know will be examined.

The top 10% of performing schools

Comment 1: It is likely that the schools that were consistently in the top 10% were those that were well equipped and well resourced. Were any of them Dinaledi schools? Since Dinaledi schools would constitute a far more representative sample, it would be useful to assess the impact of the NSC on them.

Comment 2: In determining the top 10%, did you take into account the number of students writing the examination? For example, at a school of which I am aware, of the 250 matriculants one year, five wrote mathematics HG and 30 mathematics SG. The five learners that wrote HG achieved two A symbols and three Bs, and the average pass mark for HG mathematics was thus well over 80%. The principal received many accolades, and the school became a Dinaledi school. The following year, the school entered too many learners for HG mathematics, and the average mark dropped to about 60%. In order to increase the average mark to over 70%, the school then reduced the number of learners it admitted to mathematics the following year. It should be recognised that there is considerable manoeuvring behind the statistics.

Comment 3: In order to address the issues of whether the problem lies with the system or the curriculum, the analysis of schools that consistently perform well should not shy away from closely and critically looking at instances of good practice.

It is intriguing that over the five-year period, only about 30 schools out of over 140 consistently performed well. This could mean that new schools were coming up, but they would not have been included in the five-year cohort. It might therefore be useful to conduct the analysis over a five-year rolling period in order to identify which schools are entering the top 10% bracket and which are falling out.

The top-performing schools are likely to be well resourced, and one might also find that they apply good learning models. However, there could be other hidden factors that influence their performance, for example, the impact of individual private tuition outside schools; we have anecdotal evidence that this takes place. That would thus be a model that is not sustainable across the system. The results might also relate to modes of learning that the top-performing schools encourage, for example, encouraging individual responsibility among learners for their learning.

Comment 4: Will you look at poor-performing schools? We need to contrast the schools that perform well with those that perform badly and identify what separates them.

Mr Sibanda: The results of the analysis of the best-performing schools are only preliminary, and we have not yet looked at the demographics of the schools. The analysis will be further refined. The names and codes of some schools had changed, which made it difficult to track them. The criteria excluded from the analysis any schools at which fewer than eight learners wrote a subject. It would perhaps be misleading to assess the performance of learners in mathematics paper 3, since it was optional, and learners may therefore have been less committed to a subject that did not form part of the certificate.

The results of the research on the analysis of the top-performing schools are preliminary. We also want to compare the correlation at these schools between the final mark and the continuous assessment mark. There were certain schools that performed consistently well over time but dropped only in 2008.

Chapter 8: Subject-specific issues

In this session, details of the school curricula for four learning areas were discussed. Participants divided themselves into four subject-specific groups according to their area of interest, namely, mathematics, physical sciences, life sciences and agricultural sciences. The purpose of this session was to give subject specificity to the issues raised in the plenary sessions. Sub-questions for discussion in relation to each learning area included:

- *Is the selection of core content appropriate and adequate?*
- *Are the skills that are developed appropriate and adequate?*
- *Is the relative weighting of the various learning outcomes in the final assessment appropriate?*
- *Does the syllabus provide sufficient grounding as a preparation for further study in the subject? Should that be a priority? If not, what should the priority be?*
- *The National Senior Certificate examination examines grade 12 work only. Is this appropriate? (Other African countries such as Ghana, Zambia and Kenya examine the whole senior secondary phase).*
- *To what extent does the assessment support or undermine the aims of the curriculum? What should be done differently?*

Each parallel session began with a short presentation to highlight key issues. Participants then worked in small groups to address the questions posed. Discussions were based on official curriculum and examination documents produced by the Department of Education, which had been emailed before the Forum.

MATHEMATICS

Jill Adler and Lynn Bowie

Marang Centre, University of the Witwatersrand

The following questions guided discussion on both GET and FET mathematics, as well as FET mathematical literacy.

Aims and differentiation

- Who does/should the curriculum serve?
- What purpose does the curriculum fulfil?

- Does the syllabus provide sufficient grounding as a preparation for further study in the subject? Should that be a priority? If not, what should the priority be?

- Should there be differentiation in the mathematical offerings at this level? What differentiation might be appropriate, if any? What are the pros and cons of such differentiation?

Content

- Is the selection of core content appropriate and adequate?

- Are the skills that are developed appropriate and adequate?

Assessment

- Is the relative weighting of content areas and levels of cognitive demand in the final assessment appropriate?

- To what extent does the assessment support or undermine the aims of the curriculum? What should be done differently?

The delegates at the Forum who attended the mathematics parallel session first divided into two groups, one focused on mathematical literacy – a small group; and one on mathematics. The work of the groups is captured in the report-back in plenary to the Forum at the end of the group discussions.

The groups did not follow the questions in detail but identified the general and shared issues from the discussions, including issues emerging in the Forum as a whole. We believe that we have got our shoulders to the flywheel (cf Prof. Jansen's mention of what makes for great companies) and started a process, which is very encouraging. At the end, some suggestions are made for the Forum and the ASSAf STEM Committee to take forward.

There is a general sense that the curriculum *per se* is not the problem. The following main problems were identified:

- The reality on the ground across a wide range of schools is at odds with the modern curriculum. We do not understand well enough how to move from where we are to implement the modern curriculum well across the board. We need better timeframes for doing so.

- The bigger concern, about which there is wide agreement, is that the problem with the mathematics examination was that it did not disaggregate at the bottom. Over 50% of learners failed the examination in 2008, getting less than 30% for the examination. The examination also failed to differentiate at the top; there were therefore a large number of A symbols achieved.

- The message sent by the exemplars and the optional nature of paper 3 have created lower expectations.

Recommendation 1: Taking forward the recognition of the weaknesses of the 2008 mathematics papers (at both the bottom and top ends):

- The ASSAf STEM Committee should monitor NSC examinations for demand – cognitive levels as well as mathematical problem-solving, modelling and deductive reasoning need to be included in the examination and varied (in terms of mathematical practices).

- It is recommended that during 2011, the issue of whether all aspects of the curriculum, including mathematical practices, can be assessed in the examination should be considered. By then, the ASSAf STEM Committee will have a better idea of progress in the examination process. It will then be possible to ask: "If the examination cannot examine all aspects, what is happening to the curriculum on the ground, and what do we need to do about that?"

- We believe that there could be a positive impact on the examinations from the perspective of increasing cognitive demand and including various forms of problem-solving, modelling and deductive reasoning if HEIs become involved in developing curricular materials with teachers, as well as in teacher training and identification of appropriate curriculum content. We need a broader experience and knowledge base from which to draw as we deal with this in the curriculum.

Recommendation 2: Aspects of paper 3 should be reintegrated into the core (related to geometry):

- HEIs should produce clear statements of what is to be included and justifications based on 'evidence' for this by early 2010.

- The department should commit to relevant teacher training and timelines for this in order to meet these additional requirements.

- There is disagreement as to whether data handling should be part of the core. The group does not have a firm recommendation in this regard.

Recommendation 3: There must be increased differentiation over time and in multiple ways:

- One way would be to encourage more students to do additional/advanced mathematics.

- HEIs should become involved in strengthening the pipeline from schools into university by encouraging students into the university earlier on in various kinds of programmes (for example, targeting talent activity and possibilities for learners to engage with universities from grade 10).

There was not much discussion on the following important issues:

- Mathematics, unlike the sciences, is very hierarchical, and what happens in primary school is absolutely critical to mathematics performance in secondary school. Sixty percent of primary schools are not able to support the mathematical learning that they need (analysis by Brahm Fleisch). ASSAf must take on this issue. If the focus is only at FET level, some of the root causes will not be uncovered.
- Mathematical literacy is a concern and needs fuller attention.
- Articulation between NSC mathematics and the National Curriculum (Vocational) needs to be addressed as part of the recommended differentiation.

The comment was made that if the HEIs had brought into the Forum some of the evidence from the performance of first-years in 2009, it would have been possible to have a different discussion. While that is true, it was possibly not timely, since getting our shoulder to the wheel required establishing the context for, and extent of, the systemic problems. The mathematics group recommends a follow-up Forum where evidence based on first-year progress and curriculum innovation in HEIs is collected, shared and synthesised in a way that would be productive for everybody. The topics would include what selection mechanisms were put in place for 2009, how these worked and what has been learned; and what selection mechanisms are being put in place for 2010.

PHYSICAL SCIENCES

Gilbert Onwu

University of Pretoria

The purpose of the parallel session was to give subject matter specificity to the issues raised in the plenary sessions. As a further input to the Forum, the parallel session was meant to focus more on the qualitative elements of the physical science matriculation syllabus (NCS) and its examination (NSC), in order to consider their suitability for the 21st century.

The following sub-questions were therefore formulated to elicit the views of participants:

- Is the selection of the core content of the physical science syllabus appropriate and adequate?
- Are the skills to be developed appropriate and adequate?
- Do the examination papers assess the knowledge and skills specified in the curriculum?
- Is the relative weighting of the learning outcomes in the matriculation examination appropriate?

- The National Senior Certificate (NSC) examination examines grade 12 work only. Is this appropriate?

A total of 23 participants were involved in the workshop session. Of the participants, 14 were university academic staff representing higher education institutions in six provinces, with the remaining nine representing various organisations, including the National Research Foundation, South African Institute of Physics, Umalusi, Arcelor Mittal Science Centre, Eskom, the South African Agency for Science and Technology Advancement (SAASTA) and Palama. The session was not necessarily meant to cover a representative spread of people but rather those knowledgeable about the issues, who would be likely to have research data, opinions and experience beneficial to the workshop.

The workshop began with a brief introductory presentation by the group facilitator, explaining the purpose of the session and the expected outcomes. This was followed by facilitated discussions in small groups of four to six people, dealing with each of the listed questions.

The comments and recommendations of each group were later considered by the group as a whole, and a set of recommendations were developed based on some commonly agreed issues.

On the issue of selection of core content of the physical science syllabus: Is the selection of core content appropriate and adequate?

The groups replied in qualified ways. As one group indicated, there would always be those who argue that more or less should be included. Perhaps what should be of more significance are issues dealing with sequencing, and whether core content sufficiently represents the 'big ideas' in chemistry and physics at that level. (A UNESCO report on baseline content in those subject areas is expected.) The groups, however, indicated as follows:

- The syllabus content is overloaded (especially for the number of teaching periods in the year) in both the intended and examined curriculum (the Umalusi report appears to confirm this).

- The content and actual teaching periods of the physical science syllabus is skewed towards physics.

- The syllabus may be too academically oriented, with little attention paid to those who may be more vocationally inclined.

- Time that is meant to be spent on more academically 'advanced' activities may be better used to develop more essential intellectual and practical skills.

- More clarity is required as to the purpose of the NCS in physical sciences (higher education *vs* vocational). What should be the ideal profile of a 'matric graduate in physical sciences'?

- Learning outcomes (LO1) and LO3 have been neglected – they are little examined (possibly being phased out?) because of LO2 overload.

- All skills listed in the syllabus are appropriate and adequate but would be difficult to assess.

- There is some doubt as to whether the matriculation examinations assess in a comprehensive manner the knowledge and skills listed. It is suggested that perhaps there is need to consider two examinations: one assessing mainly science process skills and relevant problem-solving skills, which could be handled internally in the form of continuous assessment; and the other, an external summative assessment at the end of grade 12.

Recommendations

- Maintain the conceptual progression (spiral physical science curriculum) as the learner moves through the grades.

- Identify and preserve core conceptual ideas – 'big ideas' in chemistry and physics in the syllabus – and grade 12 examination must reflect those ideas (by examining them). These 'big ideas' include, for instance in chemistry, the particulate nature of matter; chemical kinetics stoichiometry; macro, micro and symbolic representations of chemical processes. In physics they include a limited set of fundamental interactions and superposition of effects ('addition'), for example, forces and fields, conservation of energy and momentum.

On skills

There was general agreement that in terms of the actual curriculum document, the skills included are appropriate and adequate. The major issue was whether the examinations adequately assess them or not. The learning outcomes were further discussed, and the general observations were as follows:

- LO1 focuses on scientific investigation, but this has been diluted by 'problem-solving', not in a practical context but defined as multi-step calculations, a slippery term which perhaps actually fits across all three learning areas.

- Skills, especially practical skills, are not adequately assessed. The emphasis is more on memory-oriented academic examination.

- Continuous assessment (CASS) now forms 25% of the mark achieved by each candidate, and relates to the assessment of knowledge and skills that cannot be adequately assessed through formal external examination. Implementation of CASS is reported to be extremely variable. Many science process skills, including higher order thinking skills, should be covered in CASS.

- More time should be allocated in school/class for reinforcing the mathematics skills required for physical sciences.
- Higher education institutions should identify areas, including mathematical skills, that need to be taught at the outset to university students so as to help bridge the gap that currently exists between schools and tertiary institutions.
- Higher education ought not to drive the NCS but should focus on improving teacher education.

Recommendations

- Identify skills to be assessed on a three-year rolling basis for grades 10–12.
- Consider two examinations consisting of the following weighting: 25% CASS and 75% external examination. The science process skills and other skills should be covered and assessed in CASS.

On the NSC examination: Do the examination papers assess the knowledge and skills specified in the curriculum?

The groups replied in qualified ways here too. The examination is considered appropriate but is not in synch with the curriculum. The weighting of learning areas has been all but lost. Marissa Rollnick's analysis of NSC examinations shows that for physics, the weighting of LO3 is only about 5%, and in chemistry in the range of approximately 20–30%, including what has been variously described as 'pseudo context'.

LO3 could provide the opportunity for essays and research projects to be undertaken by students. Currently LO3 relies on CASS, but it is not effectively picked up and needs to be more integrated in the examination format as a means of building interest and motivation. This integration would perhaps mean more weighting for LO3, but the groups were not in agreement as to whether the system is ready for that.

Grades 10 and 11 are meant to focus on concepts that give rise to conceptual knowledge. Grade 12 is where integration of the knowledge and skills, including problem-solving, is supposed to occur, and LO3 ought to be the means by which to stimulate the integration in context.

In summary:

- There was general agreement backed by detailed analysis (Marissa Rolnick's group) that in terms of the curriculum, there is more conceptual testing in the National Senior Certificate examination, which is to be commended. The cognitive demand of the recent 2008 physical science grade 12 examination, according to an Umalusi study and Marissa Rolnick's analysis, is slightly higher than the old HG. This is perhaps inevitable with the new content.

- The poor results (with very low raw scores) are not useful for analysis of content validity and discrimination indices and there is therefore a need to increase the proportion of 'easy' questions, particularly in physics.

- In terms of the three-year FET qualification, there are important concepts and topics in grades 10 and 11 that are either not taught or examined sufficiently well. Perhaps the grade 12 examination should represent all three years of the NCS.

- From the perspective of the groups, that observation was considered quite reasonable and significant. How can we better enact the three-year qualification? The question is: Should higher stakes examinations, for instance, be introduced in grades 10 and 11, or should more grade 10 and 11 material be included in the grade 12 examination?

- Some groups considered it fair, reasonable and realistic to examine on only one year, precisely because the curriculum at present is not sufficiently integrated.

- Topics that are best suited to LO1 (for example, the nature of science) and LO3 (for example, science, technology and society) are meant to build interest and motivation. These topics need to be examined from an LO1 and LO3 angle and not only as LO2 topics.

Recommendation

- A three-year rolling selection of content material from grades 10–12 is proposed in which a non-negotiable core, but small content ought to be included and examined, especially for people hoping to continue in the sciences.

- A coordinated teacher education and development programme is recommended to build teacher knowledge in those areas, including studies on the nature of science and socio-scientific issues.

Some common issues among the group as a whole were identified.

Common issues

- There is need to find a way to examine aspects from the grade 10 and 11 physical sciences syllabuses.

- Overloaded content needs trimming. There is an urgent need to identify core content for the syllabus, comprising 'big ideas' in physics and chemistry.

- The cognitive level of the examination is considered appropriate and at the right level.

- Ideas are needed to assess problem-solving, LO1 and LO3. In light of the examined curriculum, it would appear that LO1 and LO3 are being phased out.

- Teacher professional development needs to be coordinated.

LIFE SCIENCES

SUMMARY OF DISCUSSION

Lorna Holtman

University of the Western Cape

In preparing for the ASSAf workshop, we focused on the New Content Framework for Life Sciences (2007). The new curriculum is a vast improvement on the older one, and the following comments should be seen as part of an ongoing process of addressing gaps both in knowledge and skills and in so doing contributing to ongoing curriculum renewal and updating.

Is the core adequate?

The intended curriculum is adequate but somewhat ambitious. The load for grades 10, 11 and 12 is heavy. The grade 12 curriculum is more extensive than the whole first-year university life sciences course.

The new curriculum is lacking in giving learners a grasp of basic chemistry. We would advise the curriculum developers to revisit the chemistry in the old curriculum. University lecturers feel the gap in chemistry knowledge among first-year students. Some universities even have a six-month chemistry course for first-year students to address the lack of background chemistry. Chemistry is needed to understand the basic concepts covered in the FET, including physiology and nutrient cycles.

There are some threads that are present in the curriculum but constitute isolated topics, for example, evolution. This is an overarching principle and should not be left as a last option in the curriculum, as at present.

There is little focus on real ecology;

There could be greater focus on ethics and human values;

There are some sequencing problems in the curriculum.

There should be more focus on structure and function, which is one of the basic tenets of morphology, yet is not visible in the curriculum. Structure and function are often separated in different grade levels (for example, grades 10 and 12). We would like to see better articulation in that regard. For example, leaf structure and photosynthesis are not covered together.

Another example of disjuncture is that the word 'mitosis' is mentioned in grade 10 without going into detail; the concept is not revisited in grade 11; and it is only 'covered' in grade 12.

There are other examples. Antibiotic resistance and immunity is done in grade 10, while the circulatory systems and the immune system are done in grade 11. Systems are thus separated from structure and function.

The skills and whether they were adequately covered

There are good opportunities in the curriculum for data handling, field work and laboratory work and for developing reading and writing skills, but it is not certain that these can be done at school level, mostly because schools are generally not resourced to enable these skills to be adequately developed. Moreover, skills development is heavily teacher dependent. What sort of training do teachers have to develop these skills? We need to make sure that teachers are better trained, prepared and actually present to teach students to develop skills.

The groups did not have a problem with the weighting of the learning outcomes in terms of the assessment, namely:

Learning outcome 1: 20% of the assessment

Learning outcome 2: 70% of the assessment

Learning outcome 3: 10% of the assessment.

Does the curriculum provide sufficient grounding for further study, and should it? If not, what should be prioritised?

The group believed that life sciences are important in preparing learners for higher education as well as for citizenship. Those should not be seen as dichotomies and should be a focus of the curriculum. However, the grounding could be better facilitated by content integration. There are various opportunities in the curriculum where one could talk about the physics, chemistry or mathematics of the topic being studied in biology, but that is not articulated in the curriculum. There are various artificial separations, for example, putting evolution at the end of the topic list.

Should the NSC examination cover the whole phase, as in other countries?

Once there is a regulatory framework in place for continuous assessment (CASS) and assurance that this is being adequately done in all schools in order to ensure that students are developing learning outcomes, there could be more emphasis on CASS. If grades 10 and 11 were to be considered as teaching and developing new concepts, and grade 12 as an opportunity to consolidate, rather than learning new content throughout the curriculum, then we could consider a phase examination, rather than a grade 12 examination. At present, the current situation is the best we can do.

Papers and arrangement of topics in the examination papers

The present situation is fine for now. As the new curriculum for life sciences is resequenced and phased in, the two papers should be swapped (paper 1 becomes paper 2 and *vice versa*), unless the advice of taking a themed approach is taken, with evolution straddling the whole curriculum (but it is considered unlikely that the department would take that approach).

The extent to which assessment undermines the aims of the curriculum

Some people felt that assessment undermines the aims of the curriculum, especially in the sense of the focus on 'teaching to the test' with respect to the high-stakes grade 12 examination.

Language of assessment

Learners are sometimes not able to articulate or even to understand what they are reading in their second language. It might be advisable to follow the recommendation of Prof. Setati and publish the examination paper in the home language and English. Research is then needed on the impact of such an approach.

A BRIEF HISTORY OF THE LIFE SCIENCES CURRICULUM FROM 2003 TO 2009

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The subject life sciences arose from an amalgamation of two previous school subjects: biology and physiology. Biology was a very popular subject choice in grades 10–12, while physiology was offered in a few schools. To mark the change from two separate subjects to one new subject, the name 'life sciences' was selected.

The National Curriculum Statement Policy Document for Life Sciences (Grades 10–12) was gazetted in 2002 after a process of development and public comment (DoE, 2003). The policy document states the aim, purpose and scope of the subject, and spells out the learning outcomes and assessment standards in great detail, with exemplars. The learning outcomes are written as follows:

> LO1: Scientific enquiry and problem-solving skills. The learner is able to confidently explore and investigate phenomena relevant to life sciences by using enquiry, problem-solving, critical thinking and other skills.

LO2: Construction and application of life sciences knowledge. The learner is able to access, interpret, construct and use life sciences concepts to explain phenomena relevant to life sciences.

LO3: Life sciences, technology, environment and society. The learner is able to demonstrate an understanding of the nature of science, the influence of ethics and biases in the life sciences, and the interrelationship of science, technology, indigenous knowledge, the environment and society.

The policy document devotes seven pages to content, which is organised into four knowledge areas:

1. tissues, cells and molecular studies;
2. structure and control of processes in basic life systems;
3. environmental studies;
4. diversity, change and continuity.

The learning outcomes were intended to be the focus of the subject, rather than the content, which was viewed as providing the context for achieving the learning outcomes. Depth was intended to be provided by the assessment standards, which progressed cognitively over the three grades, not by the content. Three or four assessment standards were written for each learning outcome in each grade, and did indeed show progression across the grades, shown by the choice of verbs, which reflected progression up Bloom's taxonomy (Bloom, 1956).

The content is described in terms of topic headings, and very little detail is provided. The content for LO2 is divided into grades, but content for LO1 and LO3 is described only in terms of the whole phase.

The policy document was followed by a more detailed Learning Programme Guidelines (LPG) document, which was revised annually for a few years (DoE, 2008a). The LPGs describe how teachers are expected to convert the policy document into a learning programme and a work schedule. The sketchy detail of the policy document is expanded for each grade. The grade specifications are quite detailed in terms of LO2, less so for LO1, and very little detail is provided in places for LO3. Teachers still have considerable latitude to choose content and activities to support learning and teaching.

A separate Subject Assessment Guidelines (SAG) document was released and revised annually (DoE, 2008b). It specifies the requirements for continuous assessment in each grade, and prescribes the format and structure of examination papers in each grade. It specifies that there should be two examination sessions in grades 10 and 11, and three in grade 12. The examination papers should be set according to a grid, giving weighting for different cognitive levels, and different types of questions. Two examination papers are to be written at the end of each year: paper 1 must cover the knowledge areas of tissues, cells and molecular studies, and structure and control of processes in basic life systems, and paper 2 must cover environmental studies and diversity, change and continuity. The weighting of the three learning outcomes is also specified, but has changed from year to year.

The effect of allocating content areas to different papers is that knowledge is compartmentalised. Genetics, for example, is included in paper 1, while evolution is in paper 2, creating an artificial separation of cognately similar topics. This reduces opportunities for integration of knowledge from different knowledge areas.

The LPGs were found to provide inadequate guidance for most teachers, so subject advisors in the various provinces drew up an 'Assessment Syllabus' for each grade, based on the content specified in the LPGs (DoE, 2006; 2007a). The assessment syllabus lists the content without consideration of learning outcomes. The content is combined into a single list, and provides the scope and depth of content for each grade. For grade 12, a national version of the assessment syllabus was produced, called 'Examination Guidelines' (DoE, 2009). This document specifies in considerable detail the content that will be examined in grade 12. Pacing is provided in terms of the number of weeks for each topic. This document provided the syllabus for the grade 12 examinations in 2008 and 2009. In the Assessment Syllabus and Examination Guidelines, the three learning outcomes have disappeared, and content appears as a long list, providing considerable detail about the content.

Due to problems identified with the content specified in the NCS and subsequent documents, a team was recruited by the DoE Deputy Director-General for FET in 2006 and asked to rewrite the content for life sciences grades 10 – 12. This task was completed in February 2007, and the resulting document was circulated to subject advisors in the provinces for comment. After a few minor adjustments, the 'New Content Framework' was gazetted in September 2007; it was officially phased in in grade 10 in 2009 and grade 11 in 2010 and will form the basis of grade 12 examinations in 2011.

The New Content Framework retains the three learning outcomes, but abandons the assessment standards. It renames the first two knowledge areas identified in the NCS policy as follows:

1. life at the molecular, cellular and tissue level;
2. life processes in plants and animals.

The names of the remaining two knowledge areas are unchanged.

The New Content Framework addresses some problems of omission in the NCS policy, such as the lack of plant biology, and the omission of attention to the diversity of life. It also dilutes the emphasis on human biology and human diseases and disorders, and structures evolution and its supporting evidence throughout the three years of study, rather than having it all appear in grade 12. Most of the concerns raised in the discussion Forum at the ASSAf STEM meeting in September/October 2009 have been addressed, as shown in Table 11.

Table 11: Concerns raised at ASSAf STEM Forum and responses from the New Content Framework

Concern raised	New Content Framework
The new curriculum is lacking in giving learners a grasp of basic chemistry.	Grade 10: Molecules of life.
… some threads … constitute isolated topics, for example, evolution. This is an overarching principle and should not be left as a last option in the curriculum, as at present.	Grade 10: History of life. Grade 11: Biogeography and body plans in animals and plants. Phylogenetic trees. Grade 12: Evolution by natural selection and supporting evidence.
There is little focus on real ecology.	Grade 10: Biomes, biospheres and ecosystems. Grade 12: Community and population ecology.
There could be greater focus on ethics and human values.	Ethics is included throughout.
There should be more focus on structure and function, which is one of the basic tenets of morphology.	Grade 10: Structure of leaf and photosynthesis. Cell structure and function. Grades 11 & 12: Structure and function of all systems in animals and plants.
… the word ‘mitosis’ is mentioned in grade 10 without going into detail; the concept is not revisited in grade 11; and it is only ‘covered’ in grade 12.	Grade 10: Cell cycle including mitosis; role of mitosis. Grade 12: Meiosis.
Antibiotic resistance and immunity are done in grade 10, while the circulatory systems and the immune system are done in grade 11.	Grade 11: Immunity and use of antibiotics. Structure and function of circulatory system, including blood.

Source: DoE (2007b)

Problems have arisen with the plethora of documents and their revision each year. Textbooks do not necessarily comply with the more detailed documents, such as the assessment syllabus and the New Content Framework. Schools that purchased text-books for the NCS in 2006 now find that the textbooks need to be replaced or sup-plemented for the New Content Framework. Many teachers are unaware that the New Content Framework exists and was supposed to have been implemented in grade 10 in 2009. Books based on the NCS 2003 are still being sold by some publishers and bookshops.

News that the Minister of Basic Education has set up review teams to revise each subject in 2010, including life sciences, is unwelcome in the current climate of over-supply of documents. The situation with regard to grade 12 life sciences examinations in 2011 is of deep concern, since there seems to be widespread ignorance of the New Content Framework. There will be some changes in the content for the grade 12 examinations in 2011, and if teachers are unaware of those changes, learners will be disadvantaged.

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AGRICULTURAL SCIENCES

EP Nel

South African Agricultural Teachers Association (SAATA)

It is sometimes believed that the agricultural sciences are not technologically equipped, but I hope to prove that wrong. Agriculture tends to be the ‘black sheep’ of the sciences.

An advertisement from the University of the Witwatersrand appeared in a recent edition of *Quest* to attract students to “exciting biological and life sciences careers”.

Mention was made of fertilisers, breeding plants and animals, the wine industry and the dairy industry. We need to redefine what constitutes ‘agricultural sciences’ and what constitutes ‘life sciences’. Agriculture is not recognised in the way it should be.

There are issues and concerns related to the agricultural sciences in South Africa, but we can all learn from one another in addressing these. A recent advertisement in one of the agricultural magazines sums up the importance of agriculture. Just as we are encountering water scarcity, we will also experience food scarcity. The land area for agriculture worldwide, including South Africa, is not increasing. Internationally, agricultural land is being eroded, and the productive land is thus diminishing. We have to produce more on the dwindling land. It is time that we start thinking about the implications of these issues for the education system.

Agricultural science is the only essential industry. In evolution, animals that did not get food simply died. Agriculture provides humans with 50 nutrients, including vitamins and minerals. If farming systems do not function, we cannot provide for that specific need. In South Africa, we know that we have to produce food. There are countless people without land. We cannot expect the people that need land to engage only in subsistence farming to provide food. It is acknowledged that there is a role for subsistence farming, but 80% of the food in the world is produced by 20% of farmers. We need to consider the role of agriculture in South Africa. Even in developed countries, such as the USA, which have enough food, that food is not properly utilised because of the prevalence of fast foods. That type of lifestyle gives rise to many diseases. If national food systems (farming systems) do not meet these demands, then:

- mortality and morbidity rates increase;
- worker productivity declines;
- livelihoods are diminished, and societies suffer.

Today, many food production systems within the developing world cannot meet the nutritional needs of the societies they support, mostly due to farming systems that cannot produce enough micronutrients to meet human needs throughout the year. Nutrition transitions (unbalanced diets) are also occurring in many rapidly developing countries, causing chronic disease such as cancer, heart disease, stroke, diabetes and osteoporosis. These global developments point to the need to explicitly link agricultural education and technologies with human health.

What agricultural subjects are offered at school (FET grades 1–12)?

Agricultural and environmental studies comprise three subjects:

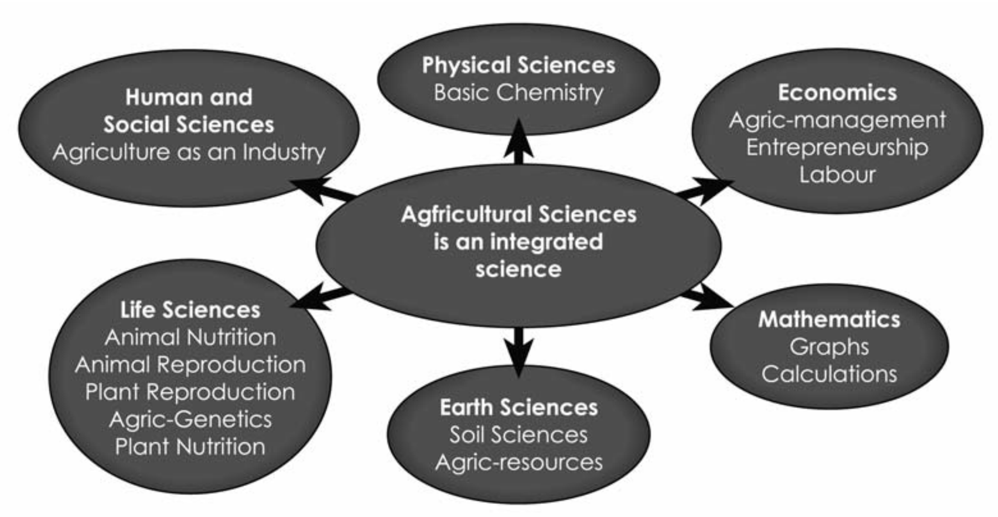
- Agricultural sciences: an integrated science, including aspects of human and social sciences, basic chemistry, ecology, genetics, agricultural economics, mathematical skills of calculation and interpretation, earth science, soil sciences and life sciences (nutrition and reproduction in plants and animals).
- Agricultural management practices (production skills).
- Agricultural technology (how to construct and maintain agriculture on a farm).

Agricultural sciences is the 13th largest matriculation subject, with about 90 000 learners enrolled in 2008. We therefore believe that agricultural sciences should be a subject in its own right, with its own national coordinator, rather than falling under life sciences. This is one of our concerns.

Agricultural sciences

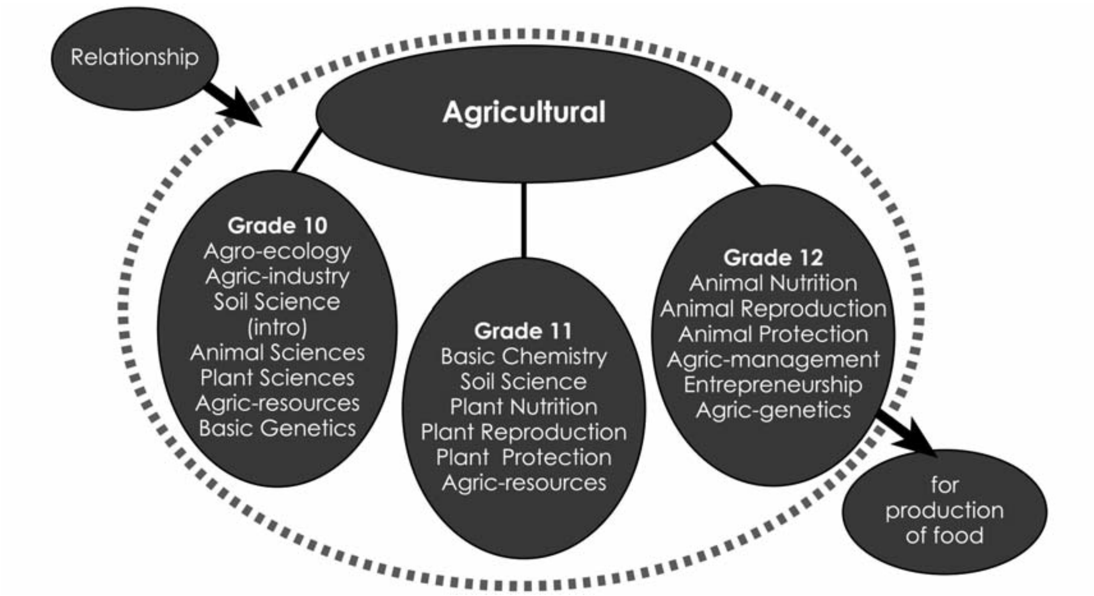
Agricultural sciences is the study of the relationship between soils, plants and animals in the production and processing of food, fibre, fuel and any other agricultural commodities that have an economic, aesthetic and cultural value. It is an integrated science that combines the knowledge and skills from physical sciences, life sciences, social sciences, earth sciences, engineering, mathematics and economics (Figure 6). This subject must be seen within the holistic science framework rather than as an isolated science.

Figure 6: Relationship between agricultural science and other disciplines



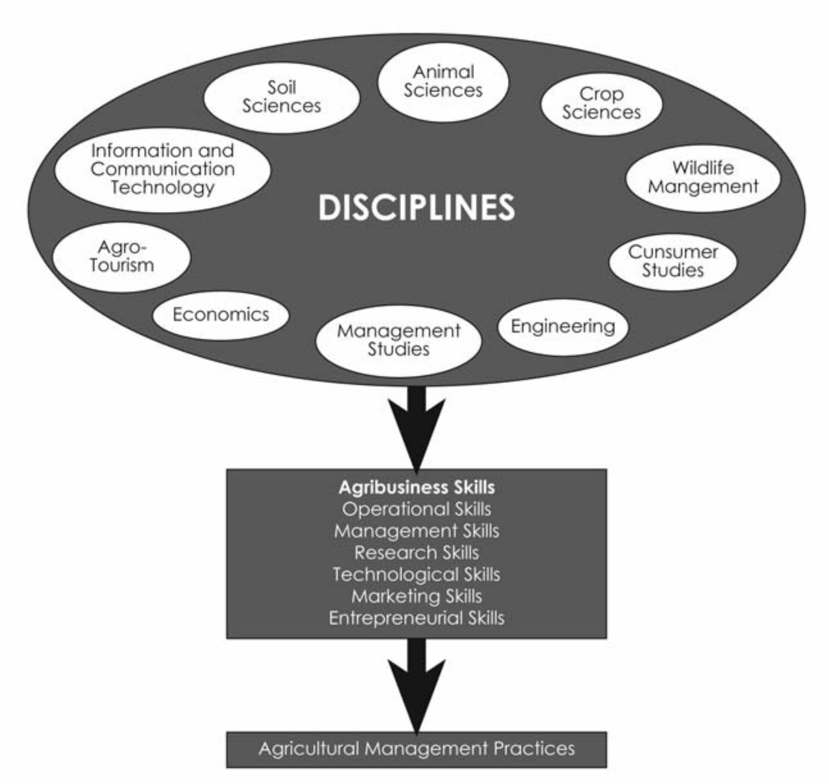
The subject of agricultural sciences seeks to inculcate an understanding of a sustainable agricultural environment by integrating theory and skills in the study of the food production chain and of processing (Figure 7).

Figure 7: Agricultural sciences content (grades 10–12)



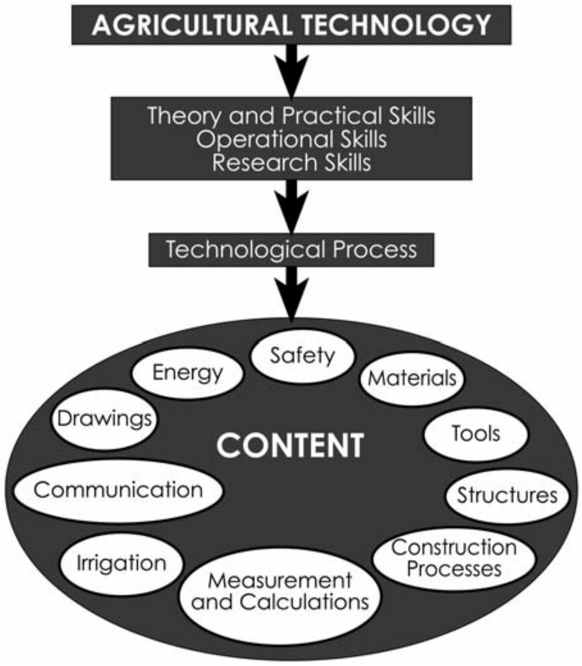
Agricultural management practices

Agricultural management practices is the study and application of economic and management principles that are used in the production, transformation and marketing of food and other agricultural products.



Agricultural technology

Agricultural technology focuses on technological processes applied in agriculture to create an understanding of how processes, equipment and structures are used together with people, soil, plants, animals and their products in order to utilise, sustain and maintain the environment.



What challenges do we face in the agricultural study field at school level and agricultural schools?

Agriculture is an expensive form of education if learners are to get practical experience of farming. The Department of Basic Education is considering the possibility of focus schools in agriculture. The national curriculum allows for streams, under one of which agriculture should fall. A focus school for agriculture should offer at least three agricultural subjects to learners. Such a school should receive special preference with respect to the teacher-to-learner ratio and the allocation of finances. At present, no agricultural school receives extra funding. There are agricultural schools on 2 300 ha, with livestock and human resources, but they are funded no differently from any other school. That is a matter of concern. We believe that focus schools could attract the support of the Department of Agriculture, Forestry and Fisheries as well as private companies.

Educators need to be trained in all fields of agriculture. It is estimated that in ten years' time, 50% of the agricultural teachers will be leaving the institutions, and there is no-one to replace them. At present, none of the South African universities offer courses for agricultural teachers.

Agriculture is not always recognised by universities for the purposes of admission, with few exceptions; for example, the University of KwaZulu-Natal. One of the universities that offers courses in agriculture stipulates life sciences rather than agriculture as a recommended subject for university entrance. These issues need to be revisited.

There is no national policy for agricultural education at school level. This also needs to be looked at. Agricultural content should be taught in context. Agriculture is a science and should be taught from that perspective. The South African curriculum for agriculture at school is on a par with the rest of the world. All the curriculum documents were presented to the universities for recommendations, and many replied that the content looked fine, but they were not really interested in the subject, although many of the universities offer agricultural streams.

Agriculture is at a disadvantage in that it is not offered as a subject in grades 8 and 9, which would prepare and encourage learners to enrol for agriculture in grades 10 – 12. We need to find a way of introducing agriculture as a subject to all learners at General Education and Training (GET) level in order to equip learners to make an informed choice about whether to pursue agriculture as a subject for matriculation.

There is no research in South Africa on agricultural education, as there has been on other scientific subjects at school level. The USA has the *Journal of Agricultural Education*, and there is much ongoing research in that country.

A general concern is that learners tend not to read, which influences their interpretation skills in case studies and influences performance in agriculture as a subject.

Core values for agriculture education and training in the FET phase

To ensure the future for agricultural schooling and training in the Further Education and Training (FET) phase, eight core values have been identified:

1. Agricultural schools have, over the course of their history, made an effective and important contribution to the agricultural value chain and are poised to make an even greater and more significant contribution in future. Sub-themes:

    - Many of the individuals who make up the backbone of agriculture in South Africa have passed through agricultural schools (where applied agricultural education and training is the main focus) on their way to entrepreneurship, leadership and success in agriculture.

    - Given the challenge facing agriculture, this rate of production, especially in previously disadvantaged communities, will have to be increased.

2. Agricultural schools have a well-defined, verifiable and widely accepted reason for existence. Sub-themes:

    - Renewed emphasis on applied agricultural education and training in developing countries (for example, Denmark and the USA).

    - The needs of organised agriculture (the aging agr-ibusiness population), i.e. producing tomorrow’s farmers today.

    - The needs of industries dependent on agriculture (many employees and leaders of agri-cooperatives and similar organisations passed through the same educational system).

- Previously disadvantaged communities and individuals can only be empowered to enter agriculture in a sustainable way if they have the capacity to manage the challenges and overcome the constraints.

- There is a perception that well-intended handovers of viable agribusinesses are facing constraints because the capacity to manage applied agriculture is absent.

- Agricultural schools are presently producing the next generation of agri-entrepreneurs, and many successes have already been documented.

- The difference between agricultural science (as provided in traditional schools) and applied agricultural science (as provided by agricultural schools)

- The Qualifications and Assessment Policy Framework Draft 3 states that "specialised schools such as arts, agricultural and technical schools, may also, subject to specified conditions, offer occupational specific programmes".

- The National Committee on Further Education for the new FET curriculum clearly states that schools with the necessary infrastructure and equipment could be allowed to offer vocational subjects.

3. Agricultural schools are critically important to stimulate and develop youth leadership in agriculture. Sub-themes:

- Future Farmers of America is an initiative launched in the USA to ensure the future of agriculture. It is no secret that agriculture is losing its appeal as far as young people are concerned. FYLIA (the Foundation for Youth Leadership in Agriculture) is a similar initiative launched in South Africa to address this particular challenge.

- The views of organisations such as the World Bank on stimulating youth participation in agriculture are well documented.

- The need for agricultural education in grades 10 –12 in South African schools was identified as early as in 1914, and in America in 1917, which show the importance of agricultural education in these grades.

- The following were proposed by the National Committee on Further Education for the new FET curriculum:

  Lay the foundation for specialist training.

  Prepare learners for further learning.

  Prepare learners for employment.

  Contribute to the economic and social development of South Africa.

These themes presuppose applied agricultural education and training.

- The same report goes on to state that, apart from the youth labour market, the irrelevance of formal schooling was a major indictment of the Senior Certificate. The syllabi did not adequately prepare and equip learners with skills required by higher education or the rapidly changing world of work.

4. Agricultural schools can act as critical resource centres within the broad education community. Sub-themes:

   - Inviting schools offering agricultural science as a subject to field visits.
   - Mentoring schools offering agricultural science as a subject.
   - Supporting agricultural colleges and faculties at universities (acting as an impor tant input source).
   - Support with the training of teachers of agricultural science as a subject.
   - Accreditation.
   - Skills training for local communities.
   - Agricultural apprenticeship training and development.
   - Agricultural rural development initiatives (University of Pretoria).
   - The Centre for Sustainable Agriculture (University of the Free State).
   - Given the challenge facing agriculture, the rate of participation, especially in previously disadvantaged communities, will have to be increased by means of courses/workshops and seminars presented at existing agricultural high schools with facilities for applied education and training.

5. Agricultural schools can contribute to, and play an important role in, the national focus on sustainable development. Sub-themes:

   - The Centre for Sustainable Agriculture (University of Free State).

6. Agricultural schools are critically related to the needs of tertiary educational institutions providing agri-science education and training. Sub-themes:

   - The perception that these institutions train and develop individuals who enter agricultural practice in large enough numbers is erroneous and misplaced. Many of the students continue to graduate and postgraduate studies and then enter the wider agri-business community, where they play a critically important role.

7. Former students of agricultural schools do not drop out of sight and out of agriculture; they form an important part of the wider agricultural value chain. Sub-themes:

- We need to solicit testimonial depositions from a wide spectrum of former students.
- Agricultural schools are home to an increasingly large number of students from Africa, in particular the SADC countries.
- There are a number of important cooperation agreements between individual schools and other countries, notably Denmark.

8. The emphasis in agricultural schools is increasingly on providing entrepreneurial skills and abilities. Sub-themes:
    - Helping individuals to create and sustain a livelihood.
    - Helping local communities to create and sustain a livelihood.
    - Relieving the burden on the state.
    - A unique agricultural ethos is fostered and built.

Who coordinates activities in agricultural schools in South Africa?

The South African Agricultural Teachers Association (SAATA) was established in 1995 to act as a forum for agricultural education at agricultural schools after financial and management support for these schools decreased. We soon realised that we had a bigger role to play and were subsequently involved in the following actions, in which we:

- Initiated the development of the subjects of agricultural management practices and agricultural technology.
- Took part in the development of these subjects by being part of the curriculum-writing sessions.
- Held biannual conferences to share information from agricultural NGOs to inform educators of the role that agriculture plays in a non-schooling situation.
- Arranged annual national subject gatherings to discuss how these subjects could be improved.
- Formed part of the ASSAf Forum in order to share concerns regarding agricultural subjects with academic institutions and determine a way forward. The deliberations would then filter through to the various provincial departments of education.
- Discussed and handed over a document addressing the management and funding of agricultural schools to the Department of Basic Education.
- Formed part of the National Agriculture Education and Training Forum, driven by

the Department of Agriculture, Forestry and Fisheries, in order to improve agriculture-related education at various levels.

- Marketed agricultural education at the NAMPO Agricultural Trade Show and the Earth-Agri Expo held in Cape Town to expose agricultural education at school level to the general public.

We in SAATA all share the following:

Vision

To be the foremost teaching association for agricultural subjects in the country.

Mission

To represent all schools and educators offering agricultural subjects and to ensure uniformity of standards in the Department of Basic Education.

Aims:

- The enhancement of agricultural education and training in and through the school, taking into consideration the national laws under the Constitution.

- The enhancement of the concerns of agricultural educators through every means determined by the association as viable.

- The promotion of agricultural, cultural and traditional methods as well as the enhancement of the newest innovations and technology in agriculture as the association sees fit.

- The enhancement of the financial services and facilities that can be considered as advantageous to a member.

- Working together with other organisations with the same aims as the association.

Chapter 9: Comments from the critical observer

STEM IN SOUTH AFRICA IN 2009: OBSERVATIONS AND REFLECTIONS OF AN OUTSIDER

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In opening the annual meeting of the British Educational Research Association in 1991, the president, Michael Bassey, identified *Three Ways of Creating Education*, which was the title of his address. The first is playing one's hunches, "by using intuition without challenge and without monitoring the consequences". The second is the historical way, "repeating what has been done before: basing one's actions on the way it was done last week or last year". The third is "creating education by asking questions and searching for evidence. It is creating education by asking about intentions, by determining their worth, by appraising resources, by identifying alternative strategies, and by monitoring and evaluating outcomes. It is creating education through systematic and critical enquiry. It is creating education through research" (Bassey, 1992: 3). While acknowledging that everyone works in the first two of these ways some of the time, he pleads for the third way as being the most potent way forward.

The ASSAf Forum almost 20 years later was all about creating education – creating educational opportunities that can, in time, bring about change in South African society. Hunches, anecdotes and observations were put forward, but not without challenge or discussion; history was invoked, but to identify the best that had happened and to distance the future and the present from the past; and above all questions were posed, intentions were examined and alternative strategies were weighed against the needs and resources of the system. It was a highly research-oriented Forum.

I describe myself as an outsider at the Forum, in that I am not native to South Africa, nor have I lived and worked here long; further, my research and teaching have been mostly in the domain of higher education, albeit on learning and teaching with the STEM subjects in focus. As such, it took a while to find out what some terms meant (to distinguish my NSC from my NCS, and what 'Dinner Lady (Dinaledi) schools' might be), and all the historical turns that had occurred – for example, the different measures that had been taken to offer compensatory programmes for those whose science and mathematics were not up to university entrance expectations. But as an outsider I had the freedom to ask naïve questions and make naïve comments publicly, so that insiders were, hopefully, given the chance to reflect anew on what might otherwise be taken as given.

As I understand, the mission of ASSAf it is to provide evidence-based advice on issues facing South African knowledge development – education, research and social development. Thus I saw my remit at the outset as being to identify what I saw during the Forum that would, through research, give evidence that could underpin the desired changes in the practices and outcomes of South African education in the areas of science, technology and mathematics, in particular in the last years of school and the first years of higher education. Throughout the meeting, I aired my thoughts and reflections on the papers and discussions, and now I have the opportunity to bring them together into a coherent whole. In this chapter, I will take on this, possibly self-imposed, task and pick up issues that grew in importance to me during the sessions and consider what research can be drawn in to a possible space of solution.

Setting the scene

The scene was set by the first evening panel presentation and discussion. The Deputy Minister of Basic Education, Mr Enver Surty, put the fundamental question forward: *Where are we now, where do we want to be, and how do we get there?* This was elaborated by Prof. John Volmink, who added that we also need to see *where we are coming from*, that a new massification is inevitable when education is made more equitably available, and that this will inevitably lead to difficulties. Where does this leave us?

The issue of resources recurred as a theme – rural schools are consistently more poorly resourced than urban schools and consistently achieve poorer matriculation results; the better-resourced Dinaledi schools, with better physical and intellectual resources, also achieve better matriculation results than demographically equivalent schools elsewhere. Better teachers are attracted to better-resourced schools, thus amplifying the problem. Where does this leave us?

A second theme that recurred was that of the perceived shortcomings of the National Curriculum Statement (NCS), its implementation and its assessment. It was claimed that the choice available for the matriculation examination enables schools to omit parts of the mathematics syllabus, which are essential not only for higher education but also for trades and their training. (The example taken up was Euclidean geometry, but this was later refuted as it was pointed out that the mathematical purpose of Euclidean geometry is to train in proof skills of the mathematician rather than in the spatial skills of the plumber.) In its implementation and assessment, there is a need for better discrimination in the light of massification. Experience showed that it has been rather easy for those at the top of the scale and too hard for poorer candidates. In application, it was pointed out and returned to several times, there is a gap between content and skills – while both are specified in the NCS, only content is adequately assessed.

What became clear to me was the inherent complexity in the system that was under discussion, made more so, rather than less, by the break in its history. The whole systemic issue has to be addressed at the same time as a number of reduced but critical issues that can, in time, interconnect to reconstitute at least a significant part of the whole.

The mission of this Forum was to look for evidence as the basis for advice, or to suggest ways of obtaining such evidence through research. How do we look for evidence that makes sense and can be used to produce advice? I was struck by several mentions of units of analysis in the talk by Dr Cassius Lubisi, and how we establish units of analysis in this huge morass of issues that we are dealing with – units that are relevant, discrete but interrelated, and researched or researchable. From the discussions on the first day, I identified four units of analysis that can provide the underpinnings, and found these reflected in the first plenary session in many respects. We need to consider how to look for evidence in these units of analysis and the relationships among them:

- **The teacher–teaching/learning–learner nexus.** This is the most focused unit of analysis. There is evidence in this unit relating to assessment; for example, how do teachers in their teaching assess the learning of the learners? How do teachers plan, enact and evaluate their lessons with respect to their learners' learning? How do learners experience the lessons, and how do they understand the knowledge and skills they meet there?

- **The school and the culture of teaching and learning.** How do schools find their way through the curriculum? How does the collective of STEM teachers in a school view and work towards learning in STEM as the focus of their teaching? How do learners and teachers work together in achieving the outcomes intended by the NCS?

- **The curriculum and the examination forms and context.** In Sweden, for example, my main place of work, there is no final examination in school, only ongoing assessment, which is, to a limited extent, normalised across the country in subjects such as mathematics, science, Swedish and English with respect to the nationally determined curriculum statements. In such a system, there are repeated opportunities to complement the learning outcomes achieved in school, so that one form of educational seamlessness can be achieved, with people entering and leaving the school and tertiary education systems at different points in their lives. How does the South African matriculation system compare with the totally continuous assessment system? What degrees of freedom are introduced in one system and the other? What limits are put on the work of the teacher and the learning of the students? What do the two systems demand of the learners, and what do they bring to the society to which the learners eventually contribute?

- **The system.** As an outsider, I had to ask what constitutes the system. It includes the political context, higher education and the leadership of schools at national, regional and local levels. Can we really analyse the system? I suggest that we should be looking for evidence at the units of individuals, structures and the curriculum in order to illuminate the system.

There are certainly other units of analysis that are needed to contribute to an understanding, and hence lay the foundation for change of the system, and the notion of *seamlessness* needs to be examined more closely. In particular, the notion of seamlessness in the education system came to me during the sessions: the potential for offering the citizens of the country the opportunity to follow their own educational trajectories in such a way that they are not disadvantaged by temporary gaps and changes of orientation or location.

What stood out for me during this initial session were the notions of important *units of analysis, the time-line of transformational practices,* and the population for which the STEM curriculum is intended. In this chapter, I will be looking for which units of analysis the plenary papers brought to light, and the ways in which the trajectory of where we are coming from, where we stand, where we want to be, and where we are going was addressed. The issue of intention of the STEM curriculum remains unclear to me – whether it is intended and enacted with higher education, or citizenship, or both in mind, though certainly it was touched upon time and again.

Contributions from the plenary sessions: observations and reflections

The five plenary sessions and the discussions in thematic groups lifted aspects of several of the units of analysis I spoke of above, and more. I am referring to my immediate reflections, my notes, my memory and my personal understanding of the content of the plenary sessions rather than the chapters that are written up here. So although I accord certain views and statements to the speakers, they have been filtered through my experience and memory!

The first plenary, from Mr Lebs Mphahlele on STEM and the National Senior Certificate (Mphahlele, 2010), belongs definitely to the unit of analysis of the system, and, for me, put flesh on Mr Enver Surty's skeleton of the trajectory of education in South Africa in recent times: where are we coming from, where are we now, and where do we want to be. With respect to *where we are coming from*, he could point to German research that South Africa has made greater progress in its reforms in the 15 years since the end of apartheid than Germany has in the 20 years since reunification. However, gaps in this progress need to be interrogated if the country is to make further progress.

I saw two issues that refer to *where we are*. The first is, is there a national crisis in education? Certainly, results of international comparative tests of science and mathematics knowledge such as the Trends in International Mathematics and Science Study (TIMSS) would indicate so, in that South African students in grades 8 and 9 performed, on average, very poorly in both 1999 and 2003 (Reddy, 2006). But, asked Mr Mphahlele, for whom are these tests being made? What attention is being paid to national aims in these internationally designed tests? Can such comparative tests actually take into account the aims for justice and transformation in the South African education system? If such tests are to paint a fair picture of the educational developments in South Africa, then they must take into account aims other than pure subject matter knowledge and ask, rather, what impact is being made with respect to these aims. The second issue I find to be of importance concerned the purpose of the National Senior Certificate (NSC) in relation to the National Curriculum Statement (NCS). In discussion, the issue of preparing students for citizenship as well as for tertiary education was taken up – somewhat related to my last point, though in national rather than international terms. Rather than being seen as an instrument for sorting those who are able to continue to tertiary education, it should be seen in the light of personal development for the nation: developing constitutional values, and lifelong learners who are confident, literate and numerate, and able to participate in and contribute to society. In a society where higher education is open to all not only by law but also thanks to the standard of basic education, this is less of a problem than in South Africa, where basic education is, at present, failing many.

On the theme of *where we want to be*, assessment is seen to play a large part. In order to raise public confidence in the state of the education system, assessor capacity needs to be developed at national, regional and district level. Assessment was also taken up in the discussion, with respect to an observed disparity between classroom and examination assessment, a slippage between vision and examination, in line with the disparity between content examination and neglect of skills that Prof. Volmink pointed to the previous evening. The curriculum is intended for citizenship, stressed Mr Mphahlele, and the history of the curriculum is such that higher education was traditionally in its sights. But at the same time that citizenship needs to be the focus, there should be more room for specialisation too, to satisfy all needs.

The second plenary, from Dr Diane Parker of the Department of Higher Education and Training, addressed issues of the quality of teaching and teacher education in the area of mathematics in particular (Parker, 2010). As part of *where we are coming from*, she pointed to the great differentiation in the qualities of teachers and teaching, and that the changed curriculum has taken the ground away from teachers who were educated under apartheid. This, on the subject of where we want to be, cannot be changed all at once. It is taking, and will take, time.

Where do we want to be? Dr Parker referred to the McKinsey report of 2007, which pointed out, hardly surprisingly, that the quality of the educational system cannot exceed the quality of the teachers, and the only way to improve outcomes is to improve the quality of instruction. She sees a need for teachers who are committed to the profession, and have a deep understanding of the subject content, ways of thinking and being, a passion for their subject and an ability to transform that subject knowledge to provide learning opportunities for their learners. Such an approach, together with content knowledge, shows itself in the ability to assess learners not only summatively but also formatively in the classroom in order to support their learning. Assessment is no longer, then, an external imposition on the learner but an ongoing relationship between teacher and learner, with knowledge in focus.

Dr Parker made several points that relate to my unit of analysis of the teacher-teaching/learner-learning nexus, from the perspective of the professionalism of the teacher. There is a two-sided dilemma: more teachers are needed, and current teachers are not necessarily those who are good role models. In order to induct new teachers into the profession and to support the existing cohort of teachers, a critical mass of good and professional teachers is necessary. She suggests master teachers who can lead developments from the inside (which is in contrast to an alternative model that is under consideration, of providing all mathematics teachers at lower grades with lesson plans to be followed slavishly). Not only master teachers but also ‘master schools’ could be possible – schools where new teachers could get good experience and where professional development can take place in good professional contexts. Her plea for teachers with passion for their subject met with criticism from the audience, as limiting the supply on the one hand and as downplaying professionalism and commitment on the other hand.

The third plenary, from Prof. Delia Marshall, dealt with the gap that is experienced when school-leavers enter higher education, and points directly to the unit of analysis of school and school culture, albeit in higher education (Marshall, 2010). This gap is not a new phenomenon, and she could point to quotations from 1936 and 1962 that could quite easily be from the newspapers of today, and nor is it confined to South Africa but is heard worldwide. She pointed out that 'Minding the gap', can have two meanings: 'minding' as in avoiding or side-stepping the gap, and 'minding' as in the sense of taking care of or attending to, which is to say in this context that higher education can either dismiss the gap from its realm of responsibility, or take on the gap as a challenge. I can add that 'minding' can also have the sense of taking exception to or disliking, and that this can point to the demand from society that the gap has to be attended to rather than avoided.

At the University of the Western Cape (UWC), the Physics Department has for years attended to the gap in isolated, and successful, ways but is now taking it on as a departmental issue. The gap, one of unpreparedness for higher education in large proportions of the entering cohort, is ultimately seen in low rates of graduation, though it appears also in the curriculum incoherence caused by students having to repeat courses after failure – only those few who go smoothly through the system experience a coherent curriculum. So *where we have been*, in this context, is developing a number of successful contributions to improved performance at entry level but still finding a gap in results. *Where we are* is owning up to the responsibility of dealing with the gap on a larger scale. And *where we are going*, in the case of UWC's physics programme, is to rethink the entire degree structure for an extended degree: not only an extra year as an add-on, which risks pushing the problems into later years, and not just an accelerated stream for the more able students, but a research-based, scholarly approach to curriculum design for a longer programme.

Three concepts in particular excited me in this programme for change, which could have implications for the rest of the education system. The first is the socio-culturally inspired creation of communities of practice, where learning is seen as accessing a disciplinary discourse through increasingly participating in activities that mirror those of practising physicists, forming an identity as a physicist. (Coming from another branch of educational research, as I do, I see here a potential gap between identity formation and physics knowledge, but, given the traditional focus placed on physics knowledge by university lecturers, I dare say that it will not be ignored at UWC.) The second is to reform the content of the physics programme to respond to new students in new times; to meet their concerns and aspirations through such content as physics in relation to climate change and democracy. The third, and potentially more far-reaching, innovation is to support and prize a scholarly approach to teaching and learning among the lecturing staff of the department. Lecturers will be encouraged to take new approaches to teaching in order to contribute to the community of physics practice, and to investigate their approaches to, and results of, teaching as well as their students' learning. The three taken together can radically change the culture of the department over the next five years, and deserve to be the object of research over that period.

Ensuing discussions took up the last point and asked how to raise the status of teaching in higher education, in contrast to research, which will almost certainly suffer from added expectations placed on lecturers in such a reform. If increased scholarship is needed and demanded in teaching higher education, then the need must be made explicit and the demand must be met by funding. Looking back on my experience in research on higher education, I have seen several reforms in Sweden. In the early 1980s, a wide-ranging reform was undertaken to improve teaching in the then-growing higher education sector, and projects were launched to research and develop specific areas. This was followed throughout the 1990s by a National Committee for Higher Education, charged with initiating and funding projects, some commissioned and others in open competition, which would introduce and study innovative teaching. In the mid-2000s, this was turned to favour distance education and, by the end of the decade, all funding and attention to teaching development had dried up at the national level. Is teaching in higher education in Sweden today as developed as it can be, and with a status on a par with research? Hardly! In Australia a similar pattern of development support was seen, though that is still continuing, if in different forms. Such reforms take time and patience, and a commitment to continuity.

The fourth plenary, from Prof. Mamokgethi Setati, took us into the classroom itself, addressing the issue of the multilingual mathematics classroom. Again, this is an issue in many countries outside South Africa but acutely felt here with many home languages that are officially South African, whereas in other countries it is mainly immigrant populations that bring new home languages into the classroom (Setati, 2010). *Where we are coming from* is a situation where language has been used as a tool for domination, whether English or Afrikaans, and *where we stand* is at the crossroads of admitting home languages into the classroom while still using predominantly English to teach and assess learning, accompanied by a public debate on the pros and cons of retaining English.

In the teacher-teaching/learner-learning nexus, the home languages must not be allowed to interfere with the mathematics and its distinct language, which has aspects of both medium and message. The problem lies, Prof. Setati states, in the intersection of mathematics, language and pedagogy. There are dichotomies and debates that make it difficult to move forward; English is seen as a social good, while the home language carries pedagogical advantages. At the heart of the problem lie socio-political and cognitive dilemmas.

Prof. Setati brought up a pedagogical point that can have implications in other dilemmas faced by education in South Africa: if language is characterised as a resource, then "it must be made visible if it is to be useful", in accordance with the work of Lave and Wenger (1991). Pointing to the direction *for the future*, she promotes a strategy of "deliberate, strategic and proactive use of home language" while retaining English as the main language of instruction, contrasting the deliberate use of home language with the "occasional, arbitrary and reactive use" in code-switching. This can be supported by such measures as parallel publishing of textbooks in English and the home language, and the development of awareness of teaching in multilingual classrooms among both experienced and student teachers. This makes the alternative use of home language visible while retaining English as the main language of instruction, and while maintaining focus on mathematics rather than on language difficulties.

Discussions point to the difficulties that might be experienced by monolingual teachers and the risk that their attempts to interact with home-language discussions could mislead learners, but this was dismissed by others in the audience with experience of having learned valuable lessons from the home-language discussions.

The fifth plenary, from Mr Emmanuel Sibanda and Ms Liz Burroughs from Umalusi, tackled the unit of analysis of the curriculum itself, in terms of content, context and examination (Sibanda & Burroughs, 2010). South Africa is moving from one form of matriculation to another that is intended to be more encompassing and offer greater opportunity to learners. This has been accompanied by considerable benchmarking and the development of benchmarking tools in order to tell exactly where the curriculum is and how it is being worked with, for the purposes of improvement. The distinction was made between the intended curriculum – what was expected of the NSC – and the assessed curriculum, through the detailed content analysis of relevant documents. Discussion brought attention to what might be called the enacted curriculum (what the teachers actually made of the curriculum in their classes) and the experienced curriculum (what the learners actually learned and understood of the curriculum).

Some concluding reflections and suggestions

My own research interests have been in learning and teaching practices in the higher education sector, especially in the mathematical, natural and engineering sciences, and only recently have I moved into teacher education and schools, so I make my reflections against that background.

Taking that as a starting point, it was Prof. Marshall's plenary that excited me most, not only – or even partially – because it dealt with physics in higher education, but because it took a holistic view of what I called the teacher-teaching/learner-learning nexus in challenging the problems of the school and the culture of teaching and learning. Here is an important lesson, as everyone realises, for education at large. These are the two units of analysis that can actually be tackled by the teaching profession itself, in close collaboration with the teacher educators and the educational researchers from the field.

First, I promote pedagogical scholarship, in line with the scholarship of teaching and learning that is taking hold in higher education (Boyer, 1990; Trigwell *et al.*, 2000; Kreber, 2002). By pedagogical scholarship, I mean the scholarship that interrogates current teaching practices and investigates the outcomes of teaching in terms of student learning, whether through classroom practitioner research or the larger-scale studies of Umalusi, as long as the teachers are engaged in – or engage with – the studies. The outcomes of such investigation and study need to be disseminated, not necessarily globally through the journals and conferences of the research community, but also locally in gatherings of teachers and decision-makers (Stenhouse, 1981). Dr Parker's suggested 'master teachers' come into this picture, who, having taken part in investigations, can support dissemination into classroom practice and further study.

Second, such scholarly work, led by master teachers as well as (or, in due course, instead of) educational researchers, and disseminated to other practitioners, leads inevitably to a community of those who are struggling to make better sense of their practices and their learners' learning – communities at the local school level, the regional level and the national level (Robertson, Galton & Hardman, 2008). When such communities and engagement are established, the profession is put on an entirely different footing than the footing of a degree and in-service courses.

Third, and leaving Prof. Marshall's presentation now, I want to draw attention to the work on 'lesson studies' that has attracted much attention since the Trends in International Mathematics and Science Studies (TIMSS). Where they were found to be commonplace, particularly in Japan, the mathematics results were significantly above the average (Stigler & Hibert, 1999). They later evolved to "learning studies" and have found a place in the research and development of classroom teaching in Sweden, Hong Kong and, latterly, Britain – albeit on a limited scale (Marton & Tsui, 2004; Lo, Pong & Pakey, 2005). In a lesson study, groups of teachers come together to discuss ways of teaching a particularly knotty area of curriculum and devise lesson plans that they each, in turn, will follow in their own classes. Lessons are observed by other members of the group, and they come together to evaluate what happened and to develop the lesson plan to improve on identified shortcomings. This has been found to be a very successful teacher and school development tool where it is practised, although the necessity for an organisational scheme where time is allotted to ongoing development through such discussions has to be noted, which is distinctly different from the scheme of South African schools and most European schools too.

The *learning study* approach is very similar, though now an educational researcher is part of the group, and the lesson area that is chosen for the study is investigated more carefully within a theoretical framework of variation theory (Marton & Booth, 1997). Variation theory has it that in order to learn something, an object of learning, you have to be able to discern its critical features and relate them to one another, both as constituents of the object of learning and as they relate to the particular context in which they appear. In order to discern something that was not visible before, it has to be kept invariant while other aspects of the object of learning and the context are allowed to vary. In a learning study, the researchers work with the teachers prior to teaching, to investigate the variation in ways in which the class already understands the object of learning, what its critical aspects are, and what needs to be brought into invariant focus during the lesson. Thus the intended object of learning is defined, and a way of enacting it is worked out. Thereafter the lesson is given by the teachers, as with a lesson study, and the lessons are evaluated and developed, as before. Finally, the object of learning as experienced by the learners is investigated with particular emphasis on the critical aspects identified earlier. This approach has been found to be very successful, in the first place, in achieving improvement in learners' learning, and some preliminary results indicate that it can particularly support the weaker learners (Runesson, personal communication). In addition, it significantly develops the teachers' approaches to teaching across the board and thus supports the development of the culture of teaching and learning in the schools involved (Rogoff, Matusov & White, 1996).

Bringing these three ideas together seems to me to be a natural research project to embark upon, involving the units of analysis of teacher-teaching/learner-learning and the culture of teaching and learning in the schools to tackle whatever the demands of the curriculum might be. The scholarship of pedagogy is engaged in through the learning study approach, thereby developing communities of learning and practice among teachers, as well as the culture of the schools. Then, the vagaries of the system as a whole can be met by a corpus of teachers with research and development experience as well as highly evolved and relevant discourses with which to tackle the discussions with policy- and decision-makers.

Returning to the opening phrases, taken from Michael Bassey (1992), this proposal is entirely in line with his third approach to creating education, in which teachers are asking the questions, engaging in systematic and critical enquiry, and creating education through research.

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Chapter 10: Conclusion and Recommendations

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In this Forum, we asked participants to consider three questions relating to school mathematics and science:

- Where are we now?
- Where do we want to be?
- How do we get there?

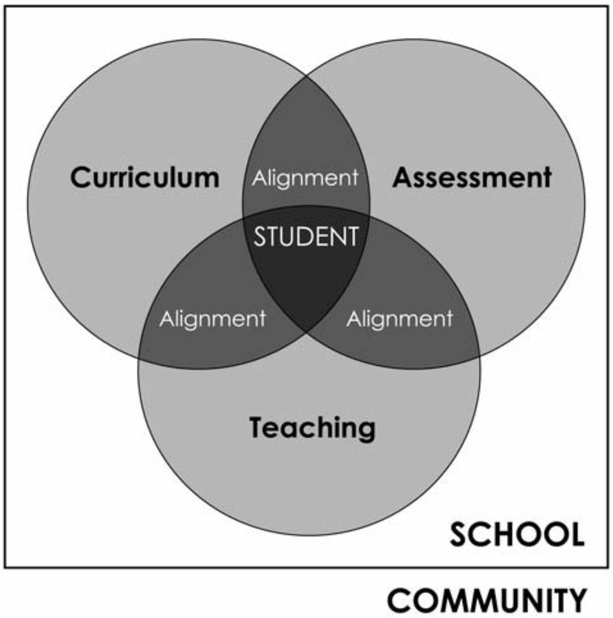
Inevitably, where we have come from – the legacy of apartheid – strongly influences where we are now. More broadly, our present position is influenced by our history, which has resulted in a diverse, multilingual, multi-ethnic society. The answers to the questions of where we want to be and how we get there, though constrained by resources, are mostly limited by our resourcefulness, imagination and will.

Presentations at the Forum addressed a variety of levels and a variety of components of the education system. In terms of levels, much of the discussion focused on the Further Education and Training (FET) (grades 10–12) band and introductory university level, including both mainstream and extended degree programmes. In terms of components, much of the discussion focused on curriculum and assessment, including how they are benchmarked, teacher education and continuing development, and teaching approaches at both school and higher education levels.

Discussions also took place about the education system. Figure 8 is a pictorial representation of the schooling system. The school is embedded within the broader community. Social issues that affect the surrounding community, such as poverty, alcohol or drug abuse and crime, affect the school. Curriculum, teaching and assessment are embedded in schools. The student experience lies at the intersection of all of these components. For there to be meaningful student learning, alignment is needed between curriculum, assessment and teaching. This must take place within a school environment that is functional; and the functionality of the school is influenced by the functionality of the community and the broader society within which it is located. As Cassius Lubisi stated (Chapter 2):

> While we are dealing with issues that are technical in nature, we cannot avoid the context-specific issues. If we are teaching children that come from poor backgrounds and are hungry, the evidence suggests that as a rule, no matter what teachers do, such children will perform badly for various reasons, including the lack of skilled teachers, the fact that the learners may not have eaten and that they do not have access to adults with knowledge to assist them with their homework.

Figure 8: Elements of the schooling system



Improving school mathematics and science means *both* improving individual components *and* improving alignment among components. Many of the activities of government and non-governmental stakeholders have focused on improving individual components of the system. For example, the process of developing new, modern, outcomes-based curricula for the FET band began a decade ago and culminated in the implementation of the new National Senior Certificate in 2008. This should have been a cause for much celebration. But there was an alignment problem. The people who developed the curricula and are responsible for overseeing their implementation in the classroom do not have readily accessible channels for communicating with the people who develop the examinations. The people who implement the curricula in classrooms all over the country and prepare students for the examinations have little or no contact with the people who develop the curricula or who set the examinations.

In another part of the education system, higher education, students who wrote the new NSC seemed less well-prepared for university-level mathematics and science than their peers a year or two before them. There was a 'gap' between schooling and higher education (Figure 9), which, while always there, seemed to have widened rather than narrowing with the changes at school level. Lack of communication between teachers and those responsible for curricula at both school and university levels appear to have led to poor alignment between the skills and knowledge students brought from school and what those in higher education expected them to bring.

Figure 9: The gap between schooling and higher education

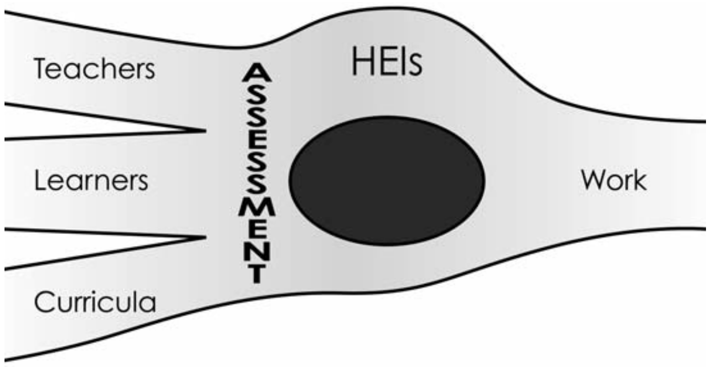
Another aspect to consider, however, is that the NSC is not intended only as a preparation for higher education. It should also prepare the majority of students who do not proceed to higher education for the world of work. How one, undifferentiated qualification can do this is an open question. The differentiation of subjects in the previous system into higher grade and standard grade, especially in mathematics, resulted in thousands of learners being excluded from opportunities for further study. How can differentiation without discrimination be introduced into the education system?

Another problem in the education system is the obstacles that exist in moving in, out and around the system. Shirley Booth (Chapter 9) made the following comment:

> In particular, the notion of *seamlessness* in the education system came to me during the sessions: the potential for offering the citizens of the country the opportunity to follow their own educational trajectories in such a way that they are not disadvantaged by temporary gaps and changes of orientation or location.

At present, this is very difficult in the South African education system. If the metaphor of water is used, we can think of three streams that lead to the final assessment at the end of grade 12: teachers, learners and curricula (Figure 10). At present, there are only two options for obtaining a qualification that allows the possibility of further study – the National Senior Certificate (schools) and the National Certificate (Vocational) (FET colleges). Following the final assessment, the river bifurcates – students choose either to further their education or go straight to work. Unlike the situation in many developed countries, in South Africa it is very difficult to move in and out of formal education and work at later stages in life.

Figure 10: The course of student progress in the education system



A central problem with a system like this is that is it underpinned by the assumption that everyone will follow the same route in more or less the same time. It does not allow for a variety of 'educational trajectories', but attempts to keep students in lock-step.

We have forgotten our own vision. In 1994 the National Commission on Higher Education (NCHE) was created by presidential proclamation. According to the Council for Higher Education (CHE, 2004), "From the NCHE onwards, key goals for transforming the institutional landscape included ... the creation of a more diverse and differentiated higher education landscape." One of the objectives of the National Qualifications Framework was to, "facilitate access to, and mobility and progression within education, training and career paths" (South African Qualifications Authority *Act 58 of 1995*).

What has happened since 1994, and especially since institutional mergers began in 2004, is exactly the opposite. Technikons, which performed a vital function as training grounds for much-needed technicians to provide technical rather than academic skills, either merged with universities or became universities of technology. Technical colleges, which, together with the apprenticeship system, provided the country with critically important artisans, have been merged and transformed into FET colleges. These colleges offer a National Certificate (Vocational), which is not an artisan qualification. Specialist colleges in agriculture and nursing are suffering from poor resourcing. Colleges of education, once spread throughout the country, were closed, their programmes taken over by universities with degree-level entrance requirements. And we wonder why we have a skills shortage.

Of course there were shortcomings in the previous education system. For one thing, it was highly fragmented. Articulation among institutional types was difficult, if not impossible. Quality assurance was a major problem, particularly at the former colleges of education. Governance was also a problem, as responsibility for different institutional types was uncoordinated and lay with too many different bodies. There is no doubt that a more cohesive higher education system was needed. The National Qualifications Framework provided a structure for creating cohesion.

But perhaps we threw the baby out with the bathwater. Instead of fixing the articulation, quality assurance and governance problems, we reduced the number of types of institutions for higher learning. Because of the higher entrance requirements of universities compared with other types of institutions, we denied access to many students who could have studied further, while at the same time increasing the calls for universities to improve their throughput rates. That is not to say that universities cannot and should not get better at teaching and looking after their students. However, academically focused programmes are not for everyone, nor should they be. While we complain about a skills shortage, we devalue skills-focused programmes as a society, and reduce opportunities for students to acquire workplace-specific skills.

South Africa is diverse in every way – ethnically, economically and geographically. A diverse nation needs diversity in its educational provision. It also needs to allow different communities of people the flexibility to do things differently. Our attempts as a nation to regulate from the top and to demand conformity are inappropriate and, as education indicator after indicator shows, unsuccessful. Ensuring quality while allowing diversity is one of our most important challenges and best hopes for successful education in the future.

Issues for further consideration

At the level of the classroom, good teaching is essential. Good teaching presupposes good teachers. As Diane Parker (Chapter 4) said,

> Unless together we ensure a supply of new teachers into the system that have the

qualities that have been identified, we will not succeed in changing the system in the long term. However, even if we do this, teachers that are deployed in schools which are dysfunctional can soon unlearn what they have been taught in their preparation and take on the characteristics of the rest of the teachers in the school, or leave the system altogether. Unless there is a critical mass of professional teachers in a school and there is good leadership, it is very difficult for new teachers to acclimatise and develop into professionals committed to their learners and their careers. Thus we have to assist teachers in the system to take responsibility for their practice and continuing professional learning. It is noted that this is not essentially about the resources that a school has, it is about ethos and commitment, although the physical and material conditions of a school do have a major effect.

For teaching to improve, education officials, universities and professional teacher organisations need to collaborate to ensure that South Africa has a corps of knowledgeable, professional and committed teachers who are able to utilise effective teaching and assessment strategies. This will require the recruitment of suitable candidates, appropriate pre-service education and continuing professional development throughout teachers' careers, and the creation of a community of practice comprising teachers who both see themselves as professional teachers and identify themselves as STEM professionals.

Unlike many other countries, both developed and developing, South Africa does not have a structure for curriculum development. As a result, for more than a decade there have been curriculum revisions and re-revisions, involving various levels of consultation. Poor articulation between curriculum developers and teachers has led to discrepancies between intended and implemented curricula. One consequence is that at the FET level, anecdotal evidence, based on first-semester university results in July 2009, suggests that students' problem-solving skills and conceptual understanding are worse than in the past rather than better.

South Africa needs to regularise curriculum development. One possible way to do this is to create a Curriculum Institute. But whether or not there is an institute, there needs to be an ongoing set of regular processes for developing and revising curricula involving government, the schooling sector, higher education and professional discipline-related organisations, such as the South African Chemical Institute, South African Mathematics Foundation and South African Institute of Physics.

Once new curricula are developed, mechanisms are needed to ensure that teachers receive training that is adequate, both in terms of time and content, to enable them to effectively implement the new curricula. Quality learning and teaching materials also need to be made available.

As with curriculum, South Africa could benefit from a semi-autonomous structure to take responsibility for assessments, such as a National Testing Centre. At present, examinations are set primarily by individuals from the schooling sector and moderated by a small number of university lecturers per subject. Too much responsibility lies in the hands of a few individuals in each subject area. A national structure would enable the establishment of a test bank of properly validated questions.

A mechanism needs to be found to ensure good communication between those who develop and implement curricula and those who develop the assessments in order to ensure good alignment. In the end, assessment, not curriculum documents, is what drives what teachers and learners choose to focus on.

At the interface between schooling and higher education, communication is needed between teachers and lecturers in order to better manage the expectations of students, teachers and lecturers.

Lecturers need to align their curricula and teaching approaches with the knowledge and skills students have when they enter higher education, rather than what they wish the students had. Lecturers also need to take the quality of their teaching as seriously as they take their research. Engaging in the scholarship of teaching and learning is as much a serious academic endeavour as discipline-based research.

The government should seriously look at creating a greater diversity of types of institution that will allow students with different aptitudes to enter a range of STEM-related jobs, including artisans and technicians, not only professionals. At secondary level, specialist schools, such as agricultural schools, should be created and provided with adequate resources to function effectively. Provision needs to be made for specialist teachers to be trained for such schools.

Finally, opportunities should be created for students of different ages and with different educational background to move in and out of the education system throughout their lives. We would all do well to revisit the vision of our newborn democracy of 1994.

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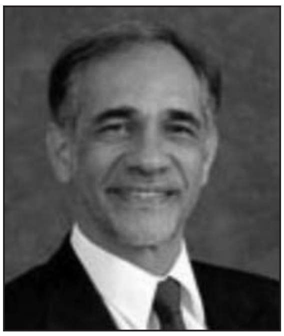
APPENDIX 1

BIOGRAPHIES OF THE INVITED SPEAKERS AND SESSION CHAIRS

Prof. Jonathan David Jansen has been Rector and Vice-Chancellor at the University of the Free State since 1 July 2009 and is also Extraordinary Professor of Education at the University of the Witwatersrand. His recent appointments include Visiting Fellow at the National Research Foundation and he is the former Dean of Education at the University of Pretoria. His new books are *Diversity High* (2008) and *Knowledge in the Blood* (2009). He holds a PhD from Stanford University and an honorary doctorate in education from the University of Edinburgh.

Prof. Roseanne Diab is the Executive Officer of the Academy of Science of South Africa and a Emeritus Professor in the School of Environmental Sciences, University of KwaZulu-Natal. She is recognised for her research contributions in the field of atmospheric sciences, particularly air quality, and more generally environmental management. She is a Fellow of the University of KwaZulu-Natal and of the South African Geographical Society. She has been a Fulbright senior research scholar, is a member of a number of international bodies such as the International Ozone Commission and the Commission on Atmospheric Chemistry and Global Pollution, and serves on the editorial board of *Atmospheric Environment*.



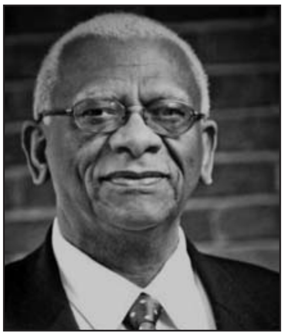
Mr Mohamed Enver Surty has a BA degree and an honours degree in philosophy, a BProc degree, an LLM degree in constitutional litigation and a postgraduate certificate in higher education. He practised law as an attorney in Rustenburg between 1977 and 1994. In 1994 he became a member of Parliament and was actively involved as a negotiator of the Bill of Rights for the ANC. In 1999 he was elected Chief Whip of the National Council of Provinces and served in that capacity until 2004. In 2004 he was appointed as the Deputy Minister of Education until September 2008, when he was appointed as Minister of Justice and Constitutional Development. He has been the Deputy Minister of Basic Education since May 2009.

Prof. Jill Adler holds the FRF Mathematics Education Chair at the University of the Witwatersrand and the Chair of Mathematics Education at King's College London. She is also a Fellow of the Academy of Science of South Africa. She leads the QUANTUM research project, the focus of which is mathematics in and for teaching, and the research and development projects within the FRF Chair. She is past Vice-President of the International Commission on Mathematical Instruction (ICMI) and recipient of both the Vice-Chancellor's Research Award and the Vice-Chancellor's Team Award for Academic Citizenship at the University of the Witwatersrand. She is the author and/or editor of three books, on teaching and learning mathematics in multilingual classrooms, professional development, and mathematics education research in South Africa.

Prof. Diane Grayson is a physicist and science educator. Currently, she is Manager for academic development at the University of Pretoria in the Faculty of Engineering, Built Environment and Information Technology and Professor Extraordinarius in the Physics Department. She was awarded a Fulbright fellowship to do her PhD in physics at the University of Washington, with a specialisation in physics education. She also has an honorary doctorate from the University of Umea in Sweden in teacher education. She served as an elected member of the International Commission on Physics Education for six years and represented South Africa twice at the General Assembly of the International Union of Pure and Applied Physics. For six years she held the education portfolio on the council of the South African Institute of Physics. In the past, she has held the positions of Professor of science education at the University of South Africa, academic Vice-Rector of the Mathematics, Science and Technology Education College and first coordinator of the Science Foundation Programme at the University of KwaZulu-Natal.

Prof. Elsabe P. Kearsley graduated in 1984 with a degree in civil engineering from the University of Pretoria. She holds a PhD from the University of Leeds. She worked as a structural design engineer in both South Africa and the UK before becoming a staff member at the University of Pretoria. She was the 2009 president of the South African Institution of Civil Engineering and is currently the Head of the Department of Civil Engineering at the University of Pretoria. For the last 15 years, she has been involved with cement and concrete materials research and she is the author of 42 peer-reviewed international conference and journal papers. Her research interests include reducing the environmental impact of concrete used for infrastructure development.

Dr R. Cassius Lubisi is Superintendent-General of the KwaZulu-Natal Department of Education. He was the project manager and chairperson of the ministerial project committee that developed the National Curriculum Statement (Grades 10–12) and was the founding chairperson of Umalusi from 2002 to 2004. He served in various capacities, including being a member of the national advisory group of the Culture of Learning Presidential Lead Project in 1995 a member of the ministerial review committee on Curriculum 2005 in 2000, and a member of the education advisory committee of the Nelson Mandela Foundation. He also served as a member of various national and international research and evaluation teams. He was a panel member of the Education sub-focus area of the National Research Foundation from 2001 to 2003. He has published various journal articles, book chapters and books. He recently co-edited, with Kader Asmal and David Chidester, a collection of human rights documents entitled *Legacy of Freedom: the ANC's Human Rights Tradition.*



Prof. John Volmink started his academic career at the University of the Western Cape and completed a PhD in mathematics education at Cornell University, Ithaca, New York in 1988. He held various teaching positions, including at the University of the Western Cape, University of Cape Town and Cornell University. Upon his return to southern Africa in 1990, he joined the University of Botswana in Gaborone. In 1991 he became involved in development initiatives in South Africa as the director of the Centre for the Advancement of Science and Mathematics Education in Durban. He later served as Pro-Vice Chancellor: Partnership at the University of KwaZulu-Natal until 2004. He is the Chairperson of Umalusi Council for Quality Assurance in General and Further Education and Training, a statutory organisation that monitors and improves the quality of general and further education and training in South Africa. He has also been centrally involved in curriculum reform in post-apartheid South Africa and has been asked by the Minister of Education to play a leading role in the transformation of education in the new South Africa. He is also the Principal and Chief Executive officer of Cornerstone Christian College. He and his wife Engela, who is also a teacher, work together in voluntary community-based educational projects in the Cape Town area with a focus on young people. He continues to provide leadership on the boards of several South African non-governmental development organisations involved in education, health and community upliftment.

Mr Lebs Mphahlele is currently a Director for curriculum design at Palama (Public Administration, Leadership and Management Academy). He holds a masters degree in education from the University of the Western Cape. The title for his research was 'The science "vacuum" in people's education: Why?' Prior to 1994, he participated in curriculum committees that 'cleansed' science syllabi of segregationist connotations. After 1994, he served as the national curriculum coordinator of SYSTEM (Students and Youth into Science, Technology, Engineering and Mathematics) (1995–1998), the chief education specialist in the Department of Education for six years (1998–2004) and the director for science and youth in the Department of Science and Technology for over four years (2004–2008). During the last 15 years, he has participated in the development, review, streamlining and strengthening of new school curricula and led the development and implementation of the National Strategy for Mathematics, Science and Technology Education, and the cabinet-approved Youth into Science Strategy.

Dr Diane Parker is Chief Director: Teacher Education in the Department of Higher Education and Training (DHET). She is responsible for overseeing the development and alignment of teacher/lecturer education policy within the framework for academic policy for higher education in South Africa; teacher/lecturer education planning and provisioning; and systems for monitoring and regulating the implementation of teacher/lecturer education policy by higher education and training institutions. Dr Parker began her career as a secondary and primary school mathematics teacher. She later moved to teaching primary and secondary mathematics student teachers. She was the head of the mathematics department at the Natal College of Education. Her work in teacher education stimulated a major interest in the design and development of teacher education curricula, and in particular the selection and coordination of knowledge and practices for teachers and teaching within formal teacher education programmes. Her doctoral research focused on the selection of knowledge and practices and the development of pedagogic identity in initial mathematics teacher education in

South Africa. She has published in the areas of mathematics teacher education, teacher education policy and practice, teacher identity and curriculum.

Prof. Mamokgethi Setati holds three professorships. She is Full Professor and Executive Dean of the College of Science, Engineering and Technology at the University of South Africa; Honorary Professor of mathematics education at the University of the Witwatersrand and Professor Extraordinaire at the Tshwane University of Technology. She has a PhD in mathematics education from the University of the Witwatersrand. She is a C1 NRF-rated scientist and a much-respected mathematics education researcher and mathematics teacher educator both nationally and internationally. She is the Co-chair of an international study entitled '(Re)sourcing mathematics teaching and learning in multilingual classrooms', which is commissioned by the International Commission on Mathematical Instruction (ICMI). She has over 35 reviewed articles published in local and international journals, conference proceedings and book chapters. She has won several awards for her research and community work, including the NSTF award for the most outstanding South African young female researcher for 2003. She has been invited as a speaker and Visiting Professor to several international conferences and universities in the UK, USA, Canada, Denmark, Italy, New Zealand, Australia, Mexico, Botswana, Namibia, Kenya, Senegal and Mozambique. She is a trustee of the Telkom and FirstRand Foundations and Vice-Chairperson of the South African board for the International Council for Science (ICSU). She served as national president of the Association for Mathematics Education of South Africa (AMESA) from 2002 to 2006, and chairperson of the board of the South African Mathematics Foundation (SAMF) from 2005 to 2006. She served as secretary and member of the executive committee of the International Group for the Psychology of Mathematics Education (PME) from 2003 to 2007.

Prof. Shirley Booth has been a Guest Professor at the University of the Witwatersrand School of Education since mid-2005, on partial leave of absence from her permanent position at Lund University in Sweden. Her research interests are clustered around issues involving learning and teaching in higher education, taking the perspective of the students and teachers through the phenomenographic research approach. Her doctoral thesis was on 'Learning to program', which reflects her own background, prior to focusing on educational issues, in mathematics and computer science. There she studied how students in the Programme of Computer Science and Engineering at Chalmers University of Technology conceptualised and learned the salient aspects of the art and/or science of computer programming. Her methodological and theoretical grounding is in phenomenography, and its concomitant theory of learning, known as variation theory. Her book *Learning and Awareness*, co-authored with Ference Marton, gives an overview of phenomenographic research oriented towards the development of variation theory. Since arriving at Wits, She has focused on the practices of learning and teaching in higher education, particularly in the South African context of transformation. While higher education is seen as a motor of transformation, and is led in this endeavour by policies at national and local level, the question that is neglected is what transformation is conceivable and viable in the pedagogical space constituted by the interactions between students, lecturers and the policies of the university. She is involved in research at Wits School of Education and the School of Engineering, some in collaboration with Swedish researchers.

APPENDIX 2

PROGRAMME

Wednesday, September 30

16:30–18:30	Registration and finger supper (Conference Centre)
18:30–19:00	Welcome Prof. Jonathan Jansen, Basic Education Deputy Minister Mr Enver Surty, Prof. Jill Adler, Prof. Diane Grayson
19:00–20:00	Invited panel discussion (Sanlam Auditorium) Prof. Elsabe Kearsley, Dr Cassius Lubisi, Prof. John Volmink
20:00–21:00	Discussion

Thursday, October 1

All sessions will be held in the Sanlam Auditorium in the Conference Centre

8:30–9:30	Plenary 1: STEM and the National Senior Certificate Mr Lebs Mphahlele
9:30–10:15	Discussion
10:15–10:45	TEA
10:45–11:45	Plenary 2: STEM teacher education Dr Diane Parker
11:45–12:30	Discussion
12:30–13:30	LUNCH
13:30–14:30	Plenary 3: STEM at the interface between school and higher education Prof. Delia Marshall
14:30–15:15	Discussion
15:15–15:45	TEA
15:45–16:45	Plenary 4: STEM and the language of instruction Prof. Mamokgethi Setati
16:45–17:30	Discussion
17:30–18:00	Summary by facilitator Prof. Shirley Booth
18:00–19:30	Cocktails

Friday, October 2

8:30–9:30	Plenary session 5: Evaluation and benchmarking of curricula (EB2-150) Mr Emmanuel Sibanda & Ms Liz Burroughs
9:30–10:15	Discussion
10:15–10:45	TEA
10:45–12:45	Parallel sessions Mathematics (Conference room 100) Physical Sciences and Technology (SRC Boardroom) Life Sciences (Postgraduate Centre 1-68) Agricultural Sciences (Postgraduate Centre 2-69)
12:45–13:45	LUNCH
13:45–14:45	Reports from parallel sessions (Sanlam Auditorium)
14:45–15:15	Summary by facilitator Prof. Shirley Booth
15:15–15:45	Discussion
15:45–16:00	Next steps and closing
16:00	TEA

APPENDIX 3

LIST OF PARTICIPANTS

Name	Organisation
Ms Elize van der Westhuizen	Agri SA
Ms Anna Tsotetsi	Agricultural Research Council
Mr Isaiah Ronald Shabangu	AMESA
Ms Elspeth Khembo	AMESA
Mr Alwyn Olivier	AMESA
Ms Sarah Morrison	Anglo American Chairman's Fund
Ms Rene van Rooyen	ArcelorMittal Science Centre
Ms Maria Botha	ArcelorMittal Science Centre
Ms Regina White	ArcelorMittal Science Centre
Mr Thami Mphokela	ArcelorMittal Science Centre
Prof. Roseanne Diab	ASSAf
Dr Nthabiseng Taole	ASSAf
Dr Xola Mati	ASSAf
Ms Zuki Mpiyakhe	ASSAf
Ms Phakamile Mngadi	ASSAf
Ms Mutheu Ngila	ASSAf
Prof. Jonathan Jansen	ASSAf/ University of the Free State
Ms Tessa Yeowart	Centre for Development and Enterprise
Prof. John Volmink	Cornerstone Christian College
Dr Diane Parker	Department of Education
Ms Penny Vinjevold	Department of Education

Name	Organisation
Dr Cassius Lubisi	Department of Education, KwaZulu-Natal
Ms Jeanette Sprinkhuizen	Department of Agriculture, Forestry and Fisheries
Ms Christa J. Havenga	Dept of Education Limpopo
Ms Votelwa Ndana	Department of Agriculture
Mr Enver Surty	Deputy Minister of Basic Education
Prof. Sibusiso Moyo	Durban University of Technology
Prof. Darren Lortan	Durban University of Technology
Mr Jonathan Muringana	Eskom
Mr John Gosling	Eskom
Mr Fred de Villiers	Eskom
Prof. Piet Human	Impala
Dr Ian Lowe	Mathematics Association of Victoria(Australia)
Dr Robin Drennan	National Research Foundation
Prof. Werner Olivier	Nelson Mandela Metropolitan University
Dr Hennie Boshoff	Nelson Mandela Metropolitan University
Prof. Gilbert Groenewald	North-West University
Ms Daleen Gerber	North-West University
Prof. Thapelo Mamiala	North-West University
Ms Jansie Niehaus	NSTF
Mr Lebs Mphahlele	Palama
Mr Patrick Hlahla	Pretoria News
Mr Dave Ryan	Royal Bafokeng Institute
Dr Jabu Nukeri	SAASTA
Dr Marietjie Potgieter	SACI
Prof. Marissa Rollnick	SACI & SAASTE

Name	Organisation
Mr E.P. Nel	SAATA
Ms Eugenie Novellie	SANBI
Dr Gustav Niebuhr	SAOU
Mr Joseph Samuels	SAQA
Mr Eddie Brown	SAQA
Ms Cynthia Xoli Malinga	Sasol Group Services
Dr Marietjie Vosloo	Sasol Inzalo Foundation
Mr David Kramer	Sci-Bono Discovery Centre
Mr Gerhard Viljoen	Settlers Agricultural High School
Dr Jackie Nel	South African Institute of Physics
Prof. Ingrid Rewitzky	Stellenbosch University
Dr Faaiz Gierdien	Stellenbosch University
Dr Kosie Smit	Stellenbosch University
Dr Jeanine Mwambakana	Tshwane University of Technology
Prof. Daniel Du Toit	Tshwane University of Technology
Prof. Willy Mwakapenda	Tshwane University of Technology
Mr Emmanuel Sibanda	Umalusi
Dr Mafu Rakometsi	Umalusi
Ms Elizabeth Burroughs	Umalusi
Ms Shaheeda Jaffer	University of Cape Town
Ms Rene' Toerien	University of Cape Town
A/Prof. Jenni Case	University of Cape Town
A/Prof. David Gammon	University of Cape Town
Mr Phumezo Kwinana	University of Fort Hare
Prof. Elizabeth Jonck	University of Johannesburg

Name	Organisation
Ms Elizabeth Burger	University of Johannesburg
Ms Annie-Helene Samson	University of KwaZulu-Natal
Prof. Paul Hobden	University of KwaZulu-Natal
Dr Fanie Terblanche	University of Pretoria
Prof. Johann Engelbrecht	University of Pretoria
Prof. Max Braun	University of Pretoria
Prof. Gilbert Onwu	University of Pretoria
Ms Kim Draper	University of Pretoria
Prof. Elsabe Kearsley	University of Pretoria
Prof. Diane Grayson	University of Pretoria
Ms Elize Randall	University of Pretoria
Prof. Mamokgethi Setati	University of South Africa
Dr Lorna Holtman	University of the Western Cape
A/Prof. Delia Marshall	University of the Western Cape
Prof. Jill Adler	University of the Witwatersrand
Prof. Shirley Booth	University of the Witwatersrand
Prof. Lynn Bowie	University of the Witwatersrand
Dr Simiso Moyo	University of Venda
Prof. Jan Ernst Crafford	University of Venda
Dr Duduzile Sibaya	University of Zululand
Prof. Ramesh Ori	University of Zululand
Dr Eunice Dlamini	University of Zululand
Prof. Sitwala Imenda	University of Zululand
Ms Heather Erasmus	Write Connection
Ms Robyn Arnold	Write Connection (Scribe)

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